ERDC/CERL TR-01-73

Construction Engineering
Research Laboratory

US Army Corps
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Low-Maintenance Remotely Monitored Cathodic Protection Systems

Requirements, Evaluation, and Implementation Guidance

Vicki L. Van Blaricum, William R. Norris,
James B. Bushman, and Michael J. Szeliga

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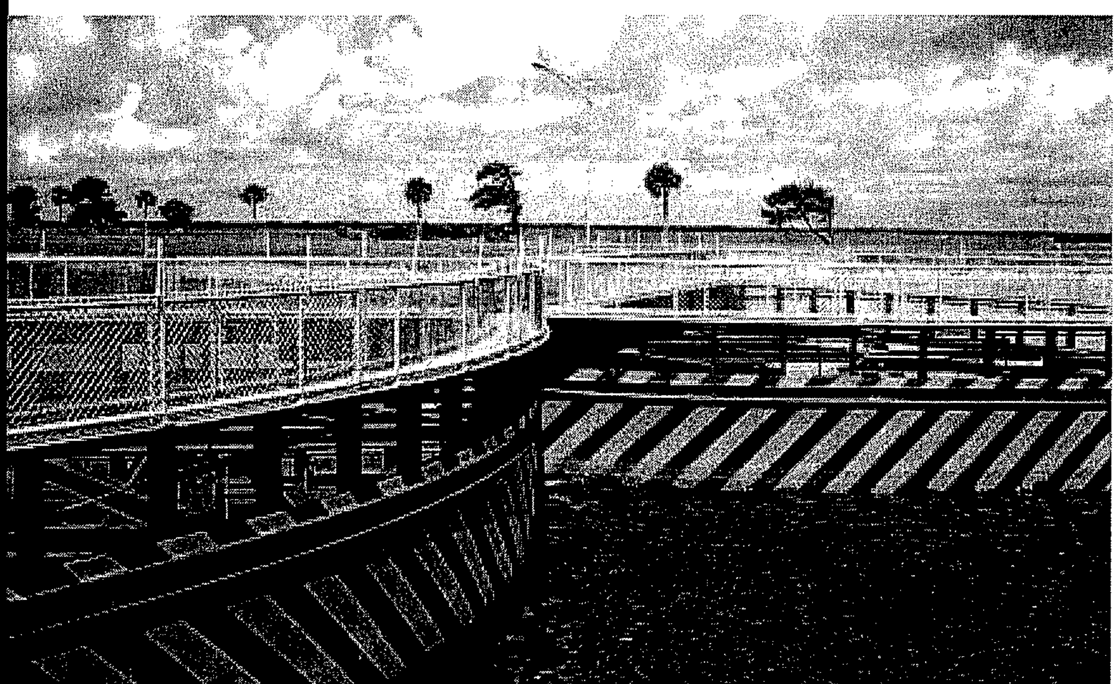

Construction Engineering Research Laboratory

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High-Performance Materials and
Systems Research Program

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Low-Maintenance Remotely Monitored Cathodic Protection Systems

Requirements, Evaluation, and Implementation Guidance

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Final report

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Under HPM&S Work Unit 33207

Foreword

The study described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the High-Performance Materials and Systems (HPM&S) Research Program. The work was performed under Work Unit 33207, "Low-Maintenance Remotely Monitored Cathodic Protection Systems," for which Ms. Vicki Van Blaricum, U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL), was the Principal Investigator.

Dr. Tony Liu was the HPM&S Coordinator at the Directorate of Research and Development; Research Area Manager was Mr. Roy Braden; and Program Monitor was Mr. Andy Wu, HQUSACE. Dr. Mary Ellen Hynes, ERDC Geotechnical and Structures Laboratory (GSL), was the ERDC Lead Technical Director for Infrastructure Engineering and Management. Mr. James E. McDonald, ERDC GSL, was the HPM&S Program Manager.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), CERL. Mr. Martin J. Savoie was Chief, CF-M, and Mr. L. Michael Golish was Chief, CF. Dr. Paul A. Howdyshell was Technical Director for the work unit, and Dr. Alan W. Moore was the Director of CERL.

Contractors working on this project were Michael J. Szeliga, P.E., vice president of Russell Corrosion Consultants, Simpsonville, MD; and James B. Bushman, P.E., president of Bushman & Associates, Medina, OH. Special appreciation is expressed to Mr. Joe Querry, CESAJ-CO-S (Canaveral Lockmaster), Ms. Shashi Makker, CESAJ-EN-DM, and Ms. Karen Estock, CESAJ-CO-S for their support of this work.

At the time of preparation of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III was the Commander and Executive Director.

Contents

List of Figures and Tables

Figures

Tables

1 Introduction

Background

Cathodic protection (CP) technology prevents corrosion of underwater and underground Corps of Engineers structures such as lock gates, bulkheads, piers, and sheet pilings. CP systems must be evaluated and adjusted regularly to make sure that they are providing appropriate levels of corrosion protection to the structure. Traditional CP evaluations are labor-intensive because they require trained technicians to travel to the structure and perform measurements with handheld meters.

Manpower limitations have made it increasingly difficult for U.S. Army Engineer Districts to conduct CP surveys. Many districts no longer have trained CP technicians on staff. Using contractors to perform these surveys is expensive and only provides one-time results. Regular CP evaluations are especially critical for civil works structures because the amount of protective current required will change significantly as the structure's coating degrades and as seasonal variations in water temperature and chemistry occur. Too much CP current can damage a structure's coating and too little current can permit corrosion to occur, so it is important to adjust the CP rectifiers as conditions change.

Several companies manufacture remote monitoring units (RMUs) designed specifically to evaluate CP systems. These units can automatically monitor multiple CP systems from a single desktop computer. This 'master' computer can be located anywhere on or off an installation — even thousands of miles away from the rectifiers and test sites. RMUs minimize the amount of time required for CP system evaluation because personnel do not need to visit the site unless a problem is detected. RMUs, therefore, make it easier to establish a regular CP testing program, and they make it possible to detect and repair CP system malfunctions quickly. RMUs can be retrofit to existing structures, or they can be installed during construction.

There are several known challenges with CP remote monitoring. Previous studies have shown that some of the RMUs on the market do not work as advertised (Van Blaricum and Norris 1997; Van Blaricum et al. 1998). Also, because RMUs are custom-manufactured, it is essential for the buyer to have accurate and detailed specifications. Furthermore, the civil works environment presents some unique challenges such as damp and sometimes salt-laden air, remote locations, and impacts from ice, debris, boats, and barges.

Objectives

The objectives of this work were to (1) evaluate commercially available CP RMUs to determine their suitability for use on Corps of Engineers civil works structures and (2) provide equipment selection and implementation guidance for Corps districts.

Approach

1. A market survey was conducted to identify candidate commercially available CP RMUs and permanent reference cells. RMU requirements were developed based on Corps needs. The three candidates that best met these needs were selected for testing. Three different permanent reference cells were selected for evaluation.

2. A testing protocol was developed.

3. Canaveral Lock in Florida was selected as the field test site. Site-specific equipment specifications were prepared and the equipment layout was designed.

4. Two RMUs from each of the three selected manufacturers were installed according to the layout drawings on the CP systems that protect the east (i.e., oceanside) sector gates at Canaveral Lock.

5. RMU readings were compared with manual readings taken onsite to determine the accuracy of the RMU measurements. Readings were taken remotely on a weekly basis to verify consistency of performance.

6. Units were compared in terms of other features such as ease of installation, software capabilities, and quality of documentation. These results were used along with the field measurement results to provide a comprehensive evaluation of the three units.

7. Results and lessons learned were documented, and selection guidance was prepared.

Scope

This study should not be considered all-inclusive. It includes only the CP RMUs that met specific criteria at the time of the manufacturer survey in 1999. These requirements are listed in Chapter 3. There were systems available at the time of the survey that did not fully meet these requirements, but may meet them now. Furthermore, other manufacturers may have introduced new systems onto the market since the time of the survey.

The hardware that was tested was procured in early 2000 and can be assumed to be representative of the hardware that was available from the manufacturers at that point in time. Some of the manufacturers may have updated or improved their hardware since that time, but these updates are not addressed in this study.

Mode of Technology Transfer

It is recommended that Unified Facilities Guide Specification (UFGS) 13113A and Engineer Manual (EM) 1110-2-2704 be updated to incorporate the findings of this work. Information on CP remote monitoring, including the results of this work, will be presented during the annual PROSPECT* Corrosion Course and the annual Facilities Engineer Corrosion Course offered at the Construction Engineering Research Laboratory, Champaign, IL. Further information on the project is posted on the World Wide Web at the ERDC-CERL Utilities System Management and Analysis Tools web page:

http://www.cecer.army.mil/usmt/CP/RemCPmonitor.htm

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* PROSPECT: Proponent Sponsored Engineer Corps Training

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 ft	=	0.305 m
1 yd	=	0.9144 m
1 sq in.	=	6.452 cm^2
1 sq ft	=	0.093 m^2
1 cu in.	=	16.39 cm^3
1 cu ft	=	0.028 m^3
1 lb	=	0.453 kg
1 psi	=	6.89 kPa
°F	=	(°C x 1.8) + 32

2 About CP Remote Monitoring

Cathodic Protection

CP is an electrical method of mitigating corrosion on structures that are exposed to electrolytes. Corrosion control is achieved by forcing a proper amount of direct current (DC) to flow from auxiliary anodes through the electrolyte and onto the structure to be protected.

CP systems must be monitored periodically to ensure that they are providing proper corrosion protection. A typical impressed current CP evaluation includes analysis of structure-to-electrolyte potential measurements (both "on" potential and "instant-off" potential, or IOP) and rectifier input and output measurements.

Basic information about CP and procedures for evaluating CP systems can be found in a variety of publications, including MIL-HDBK 1004/10, EM 1110-2-2704, and ETL 1110-9-10.

Basics of CP Remote Monitoring

Remote monitoring systems allow users to measure, transmit, and receive information from a distant location. They can be used for data collection, alarms, and control in a variety of industries. For example, operators of water distribution systems might use remote monitoring to measure the water level in a storage tank and to sound an alarm at the water plant when the level drops below a specified volume.

CP remote monitoring units (RMUs) are usually installed near the CP rectifier. A schematic is shown in Figure 1. Permanent reference electrodes are mounted near, but not touching, the protected structure, and their lead wires are routed to the RMU. The terminals of the RMU are connected to the CP equipment and protected structure so that the desired measurements can be made. Many RMUs are equipped with a relay to interrupt the CP current so IOP can be measured. The RMU contains a modem that enables it to communicate via standard telephone lines or cellular phone. The user then obtains the data via a modem-equipped personal computer with special software that is provided by the RMU manufacturer.

Most CP RMUs can monitor the following parameters:

- **Structure-to-soil "on" potential**: This is the potential of the protected structure with the CP current applied. This potential is usually referenced to a copper / copper sulfate ($Cu/CuSO_4$) reference electrode.
- **Structure-to-soil "instant-off" potential**: This is the potential of the protected structure immediately after the CP current is interrupted. The potential is usually referenced to a copper / copper sulfate ($Cu/CuSO_4$) reference electrode.
- **Rectifier DC voltage**: This is the output voltage of the rectifier as measured across the output terminals.
- **Rectifier DC current**: This is the output current of the rectifier. It is usually determined by measuring the voltage drop across a shunt of known resistance and applying Ohm's Law.
- **Rectifier AC (alternating current) voltage**: This is the input voltage to the rectifier, and will usually be 120 or 240 V AC.

Safety

Installation and configuration of CP RMUs require working with electrical systems, and may include exposure to high voltages. This work should only be done by qualified personnel, and all standard safety procedures for electrical work should be followed.

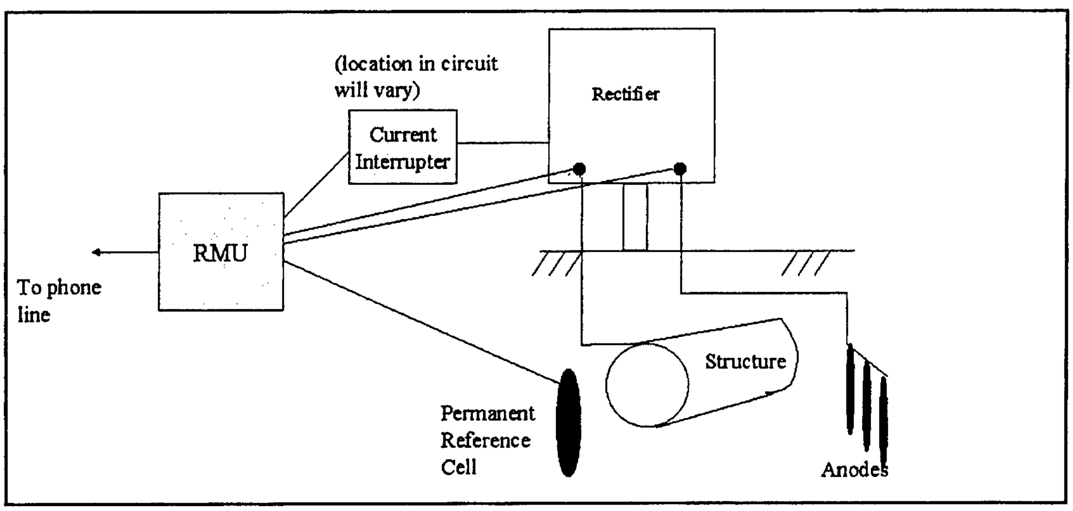

Figure 1. General cathodic protection RMU schematic.

3 Market Survey

Procedure

A market survey was conducted to identify candidate commercially available CP RMUs and permanent reference cells. RMUs were evaluated according to the following criteria:

- must be able to measure on-potential, instant-off potential, and rectifier inputs and outputs without significant hardware modifications or programming
- must be compatible with multiple brands of CP equipment so that it can be retrofitted to existing CP systems
- must be competitively priced
- must have surge protection on all data channels, power supply, and phone line
- must be currently ready for production*
- must be capable of cellular phone communication
- must be solar-power capable to allow use at remote sites.

Initial RMU Manufacturer Survey

An initial survey of corrosion control and monitoring equipment companies was conducted in early 1999 to determine the potential sources for commercially available remote monitoring systems. Following is a list of the 26 companies contacted and the results of the survey.

* Previous studies found that some companies advertised systems before they were ready to be used (Van Blaricum et al. 1998).

Aerotron-Repco, Inc., Orlando, Florida

This company manufactures an FM (frequency modulation) radio modem communication device with limited range. They do not manufacture remote monitoring systems for CP.

Allied Corrosion Industries, Inc., Marietta, Georgia

This company does not manufacture remote monitoring systems. They are a distributor of the M.C. Miller DAX system.

BAC Corrosion Control, Inc., Telford, United Kingdom

This company does not manufacture remote monitoring systems.

Bass Trigon Software & Remote Monitoring, Inc., Longview, Texas

This company does not manufacture remote monitoring systems. However, it does have a computer program for accessing RMUs that are produced by Corexco, Inc.

Borin Manufacturing, Inc., Bel Air, California

This company distributes the Comanche RMCS, which is manufactured in Germany. They also distribute custom software for use with the Comanche RMCS RMU. Their system was considered a viable candidate for further evaluation.

Brance-Krachy Company, Inc., Houston, Texas

This company does not manufacture remote monitoring systems. They are a distributor of the M.C. Miller DAX system.

Cathodic Protection International, Aps., Vallensbaek Strand, Denmark

This company manufactures remote monitoring systems that are geared to CP for reinforced concrete structures. Their equipment is manufactured in Denmark and the survey team was unable to locate a distributor based in the United States. Their systems are reportedly limited in application for other types of CP and are therefore not suitable for consideration as part of this evaluation.

Cathodic Technology, Ltd., Bolton, Ontario, Canada

This company manufactures the Cath-Tech RMU remote monitoring system. Their equipment is manufactured in Canada but the survey team was unable to locate a distributor based in the United States. Limited information was available about this system at the time of the survey.

Corrosion Control Services, Ltd., Wolverhampton, England

This company does not manufacture remote monitoring systems.

Corrosion Service Company, Ltd., Downsview, Ontario, Canada

This company manufactures the RMU2 and Status Module remote monitoring systems and software. They also supply software for use with other remote monitoring systems. Their system was considered a viable candidate for further investigation as part of this evaluation.

Corexco, Inc., Montreal, Canada

This company manufactures the Cord-3 and Cord-4 remote monitoring systems and software. Their policy is that the systems will be sold only with a minimum four-day training package included in the purchase price to the customer. Given the cost burdens and restrictions that they place on the purchase of their equipment, this system was not considered for further evaluation.

Cyberdan, Denmark

This company manufactures the Cyberdan LRU remote monitoring system that is geared to CP of reinforced concrete structures. Their system is reportedly limited in its application for other types of CP systems. Their equipment is manufactured in Denmark and the survey team was unable to locate a distributor based in the United States. Because of the difficulty of obtaining the system in the United States, it was not considered for further evaluation.

Dynamics, Ltd., Bristol, England

This company manufactures the EDLARM remote monitoring system and software that is geared primarily for use with the rectifiers that they manufacture. This system was not considered for further evaluation due to its limitation to a single brand of rectifiers.

Farwest Corrosion Control Company, Inc., Gardenia, California

This company does not manufacture remote monitoring systems. They are a distributor of the M.C. Miller DAX system.

Fera, Inc., Houston, Texas

This company manufactures the Freedom remote monitoring system and software. They also distribute the Metretek CPM-II system with their own monitoring software. The Freedom remote monitoring system was considered a viable candidate for further investigation as part of this evaluation.

Good-All Electric, Inc., Medina, Ohio

This company (owned by Corrpro Companies, Inc.) manufactures the RAMS remote monitoring system and software. The RAMS unit performed poorly during a previous evaluation (Van Blaricum and Norris 1997). At the time of the manufacturer survey, it was reported that Good-All Electric had been shut down and its production responsibilities had been shifted to a Canada-based company. The status of the RAMS remote monitoring system could not be determined. Due to these corporate changes and uncertainty about the product's future, the RAMS system was not considered a likely candidate for further evaluation.

Hutton Communications, Inc., Dallas, Texas

This company manufactures systems for monitoring oil and gas flow, telemetry data, and railroad data. Their equipment is not specifically geared to the monitoring of CP systems.

JA Electronics Manufacturing Company, Inc., Stafford, Texas

This company manufactures the WinPac remote monitoring system and software. Their system performed well in a previous evaluation (Van Blaricum et al. 1998), and had reportedly been modified and improved since the previous CERL evaluation. This system was considered a viable candidate for further investigation.

M.C. Miller Company, Inc., Vero Beach, Florida

This company manufactures the DAX remote monitoring system and software. Their system was successfully evaluated under previous CERL projects, and had reportedly been modified and improved since the previous evaluation. This system was considered a viable candidate for further investigation.

MESA Products, Inc., Tulsa, Oklahoma

This company does not manufacture remote monitoring systems. They are a distributor of the M.C. Miller DAX system and the Borin Comanche RMCS system.

Metretek, Inc., Melbourne, Florida

This company manufactures the CPM-II remote monitoring system and software. Their system performed well in a previous evaluation (Van Blaricum et al. 1998), had reportedly been modified and improved since the previous evaluation. This system was considered a viable candidate for further investigation.

Orbital Sciences, Inc., Dulles, Virginia

This company provides global satellite communications. They do not manufacture remote monitoring systems for CP.

Remco Systems, Ltd., Birmingham, England

This company manufactures the REMCO remote monitoring system and software. Limited information was available for this system at the time of the survey and it was not considered for further evaluation.

Stuart Steel Protection Company, Inc., South Bound Brook, New Jersey

This company does not manufacture remote monitoring systems. They are a distributor of the M.C. Miller DAX system, the Borin Comanche RMCS system, and the Corexco Cord-4 system.

Tomar Systems, Inc., Grayslake, Illinois

This company no longer manufactures remote monitoring systems for CP. The Tomar systems performed poorly during a previous study (Van Blaricum and Norris 1997).

TransWave International, Inc., Dayton, Ohio

This company manufactures a system for remotely monitoring specific waveforms on cathodically protected pipelines. Their system is not designed for directly providing CP rectifier outputs and structure potential data, so it was not considered for further evaluation.

Candidate RMUs for Further Evaluation

The initial survey produced a list of seven candidate systems for further evaluation. Specifications for the seven systems are shown in Table 1 through Table 6. Since the project budget allowed evaluation of only three different manufacturer's systems, candidate system rankings were based on system features, software configurations, and applicability to CP systems on civil works structures. The systems were rank-ordered as follows:

1. M.C. Miller Company, Inc.: DAX, U.S. manufactured.
2. Metretek, Inc.: CPM-II, U.S. manufactured.
3. Borin Manufacturing, Inc.: Comanche RMCS, German manufactured.
4. Corrosion Service Company, Ltd.: RMU2, Canadian manufactured.
5. JA Electronics Manufacturing Company, Inc.: WinPac, U.S. manufactured.
6. Corrosion Service Company, Ltd.: Status Module, Canadian manufactured.
7. Fera, Inc.: Freedom, U.S. manufactured.

The top three candidate systems were selected for evaluation. These were (1) M.C. Miller DAX, (2) Metretek CPM-II, and (3) Borin Comanche RMCS.

Table 1. Specifications for Borin Comanche.

Number of Data Channels	4 to 32
Negative and Positive for Each Channel	Yes
Standard DC Voltage Ranges	100 mV, 4 V, 5 V, 10 V, 30 V, 100 V, 200 V, 20 mA
Standard AC Voltage Ranges	Auto Detect Only
Optional DC Voltage Ranges	None
Input Impedance	1 Megohm, 20 Megohms
Compatible with Multiple Manufacturers' CP Equipment	Yes
Power Supply Lightning Protection	Yes
Telephone Lightning Protection	Yes
Data Channel Lightning Protection	Yes
Installation/Training Required by Manufacturer	No
Windows or DOS	Windows
Internal Modem	Yes
Modem Transmission Rate	2400 Baud, 9600 Baud Option
Instant Off (IR Free) Readings	Yes
Cellular Phone Option	Yes
Solar Power Option	Yes
Base Package Cost	$1,000 to $3,000
Country of Manufacture	Germany, USA Distributor

Table 2. Specifications for systems from Corrosion Service Company, Ltd.

RMU Model	Status Module	RMU2
Number of Data Channels	6	15
Negative and Positive for each Channel	Yes	Yes
Standard DC Voltage Ranges	2 V, 1 mV	2 V, 1 mV
Standard AC Voltage Ranges	Optional Auto Detect Status	Optional Auto Detect Status
Optional DC Voltage Ranges	0.1 mV Voltage Divider for Higher Voltages	0.1 mV Voltage Divider for Higher Voltages
Input Impedance	10 megohms	10 megohms
Compatible With Multiple Manufacturers' CP Equipment	Yes	Yes
Power Supply Lightning Protection	Yes	Yes
Telephone Lightning Protection	Yes	Yes
Data Channel Lightning Protection	Yes	Yes
Installation/Training Required by Mfr	No	No
Windows or DOS	Windows	Windows
Internal Modem	No*	Yes
Modem Transmission Rate	Tone Transmission	14400 Baud
Instant Off (IR Free) Readings	Optional	Optional
Cellular Phone Option	Yes	Yes
Solar Power Option	No	No
Base Package Cost	$500 to $750	$1,200 to $1,400
Country of Manufacture	Canada, USA Distributor	Canada, USA Distributor

* Special Xcom modem card must be installed in computer to allow communication.

Table 3. Specifications for Fera Freedom.

Number of Data Channels	3
Negative and Positive for Each Channel	No
Standard DC Voltage Ranges	100 mV, 5 V, 100 V
Standard AC Voltage Ranges	Auto Detect Only
Optional DC Voltage Ranges	None
Input Impedance	100,000 ohms, 10 Megohms
Compatible With Multiple Manufactures' CP Equipment	Yes
Power Supply Lightning Protection	Uses Rectifier Protection
Telephone Lightning Protection	Yes
Data Channel Lightning Protection	Surge Protection
Installation/Training Required by Manufacturer	No
Windows or DOS	Windows
Internal Modem	Optional
Modem Transmission Rate	1200 Baud
Instant Off (IR Free) Readings	No
Cellular Phone Option	Yes
Solar Power Option	Yes
Base Package Cost	$500 to $700
Country of Manufacture	USA

Table 4. Specifications for JA Electronics WinPac.

Number of Data Channels	5
Negative and Positive for Each Channel	No
Standard DC Voltage Ranges	50 mV, 2.5 V, 400 V
Standard AC Voltage Ranges	None
Optional DC Voltage Ranges	Any up to 400 V
Input Impedance	1000 ohms, 1 and 100 Megohms
Compatible With Multiple Manufactures' Cathodic Protection Equipment	Yes
Power Supply Lightning Protection	Uses Rectifier Protection
Telephone Lightning Protection	Yes
Data Channel Lightning Protection	Surge Protection
Installation/Training Required by Manufacturer	No
Windows or DOS	Windows
Internal Modem	Optional
Modem Transmission Rate	1200 Baud
Instant Off (IR Free) Readings	Optional
Cellular Phone Option	Yes
Solar Power Option	Yes
Base Package Cost	$1,000 to $2,000
Country of Manufacture	USA

Table 5. Specifications for M.C. Miller DAX.

Number of Data Channels	4 to 8
Negative and Positive for Each Channel	Yes
Standard DC Voltage Ranges	Auto Ranging 40 mV, 400 mV, 4 V, 40 V, 400 V
Standard AC Voltage Ranges	Auto Ranging 40 mV, 400 mV, 4 V, 40 V, 400 V
Optional DC Voltage Ranges	None
Input Impedance	10 Megohms, 400 Megohms
Compatible With Multiple Manufactures' Cathodic Protection Equipment	Yes
Power Supply Lightning Protection	Yes
Telephone Lightning Protection	Yes
Data Channel Lightning Protection	Yes
Installation/Training Required by Manufacturer	No
Windows or DOS	Windows
Internal Modem	Optional
Modem Transmission Rate	1200 Baud, 9600 Baud Option
Instant Off (IR Free) Readings	Optional
Cellular Phone Option	Yes
Solar Power Option	Yes
Base Package Cost	$500 to $3,000
Country of Manufacture	USA

Table 6. Specifications for Metretek CPM-II.

Number of Data Channels	7
Negative and Positive for Each Channel	3 Channels Yes, 4 Channels No
Standard DC Voltage Ranges	100 mV, 3 V, 50 V, 75 V, 200 V
Standard AC Voltage Ranges	Auto Detect Only
Optional DC Voltage Ranges	None
Input Impedance	1 Megohm, 10 Megohms
Compatible With Multiple Manufactures' Cathodic Protection Equipment	Yes
Power Supply Lightning Protection	Optional
Telephone Lightning Protection	Yes
Data Channel Lightning Protection	Optional
Installation/Training Required by Manufacturer	No
Windows or DOS	Windows
Internal Modem	Yes
Modem Transmission Rate	2400 Baud
Instant Off (IR Free) Readings	Optional
Cellular Phone Option	Yes
Solar Power Option	Yes
Base Package Cost	$1,500 to $3,000
Country of Manufacture	USA

Permanent Reference Cells

Three candidate manufacturers of permanent reference cells were identified during the manufacturer survey. The project budget allowed all three manufacturers to be included in the evaluation. The manufacturers are Borin Manufacturing, Inc.; Matcor, Inc.; and Electrochemical Devices, Inc. (EDI).

4 Canaveral Lock Field Test Site

Background

Canaveral Lock, FL, was selected as the field test site for the CP remote monitoring equipment. This site was chosen because the combination of high temperatures, high humidity, high chloride content of the air and water, and frequent thunderstorms comprise a particularly severe test environment for this type of equipment. Most Corps hydraulic structures are located in less severe fresh water environments. However, since only one test site could be constructed within the budget of the project, it was decided to conduct the test in the most severe environment available. If a system can withstand and function properly in such a harsh test environment, then it is reasonable to assume the same system could operate successfully in less severe fresh water settings.

The lock, located in Brevard County, FL, near Cocoa Beach and Port Canaveral, allows watercraft to pass between the Atlantic Ocean and the Banana River. A pair of sector gates (Figure 2) is located at each end of the lock chamber. Separate impressed current CP systems are installed on each of the four gates. Each system is powered by its own eight-circuit rectifier located inside the gate's machine house (Figure 3). The submerged portions of the skin side of the gates are protected by ceramic-coated disk anodes. On the structural compartment side, the submerged portion is protected by ceramic-coated rod anodes. Site personnel reported that the CP system was installed in approximately 1988.

Test Site Layout and Design

Original Site Design

An initial site survey of Canaveral Lock was performed in late November 1999 by a contractor. The objectives of the survey were to obtain enough information to develop a test site layout and to prepare ordering specifications for the RMUs.

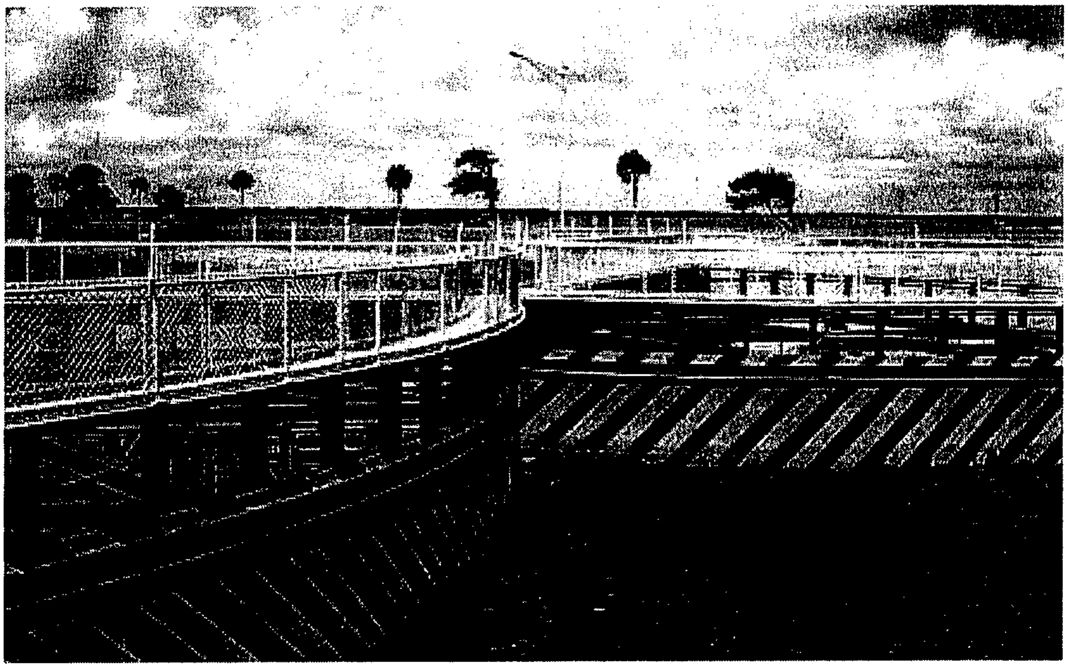

Figure 2. Sector gates at Canaveral Lock, FL.

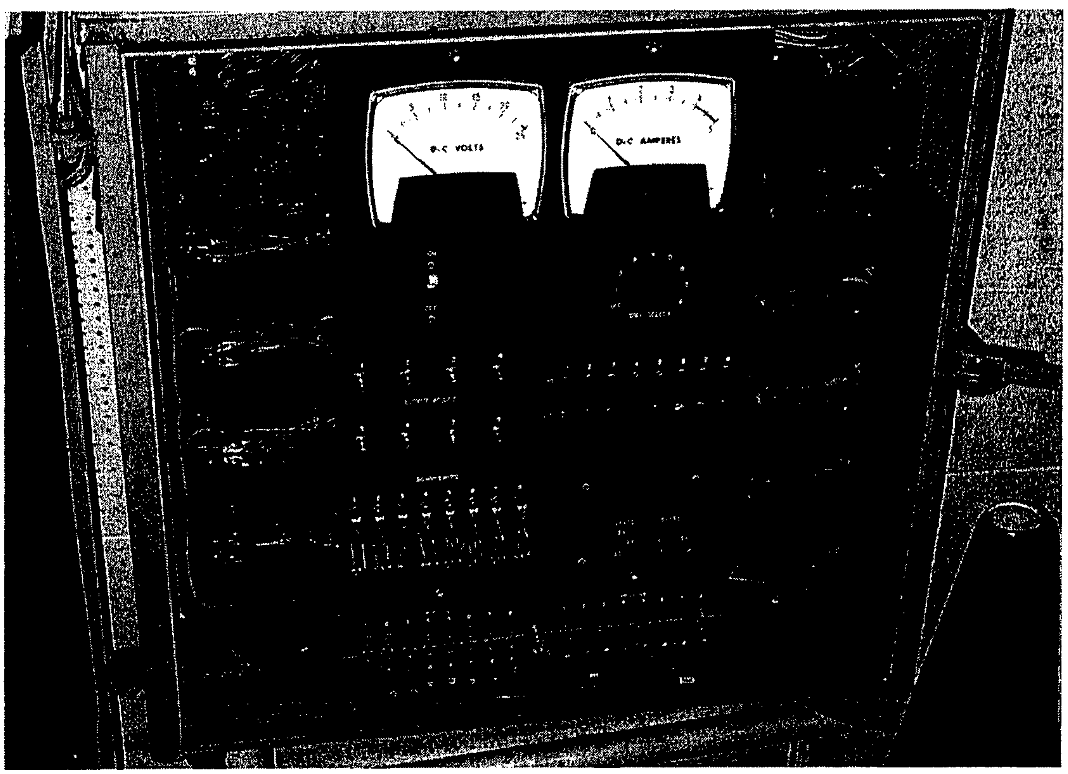

Figure 3. Interior of eight-circuit rectifier at Machine House 1.

The project budget allowed the purchase of two RMUs from each of the three manufacturers. The original test site plan (Figure 4) was to install the two Metretek units on Gate 1, the two M.C. Miller units on Gate 2, and the two Borin units on

Gate 3. Two of each of the three brands of permanent reference cells were also to be installed on each gate.

The test site was originally designed so that each manufacturer's RMU would monitor at least one reference cell from each reference cell manufacturer. Figure 5 shows the reference cell mounting locations. Figure 6 and Figure 7 show the original design for shields devised to protect the reference cells from damage by debris in the water. Figure 8 is a detailed drawing of the reference cell hangers.

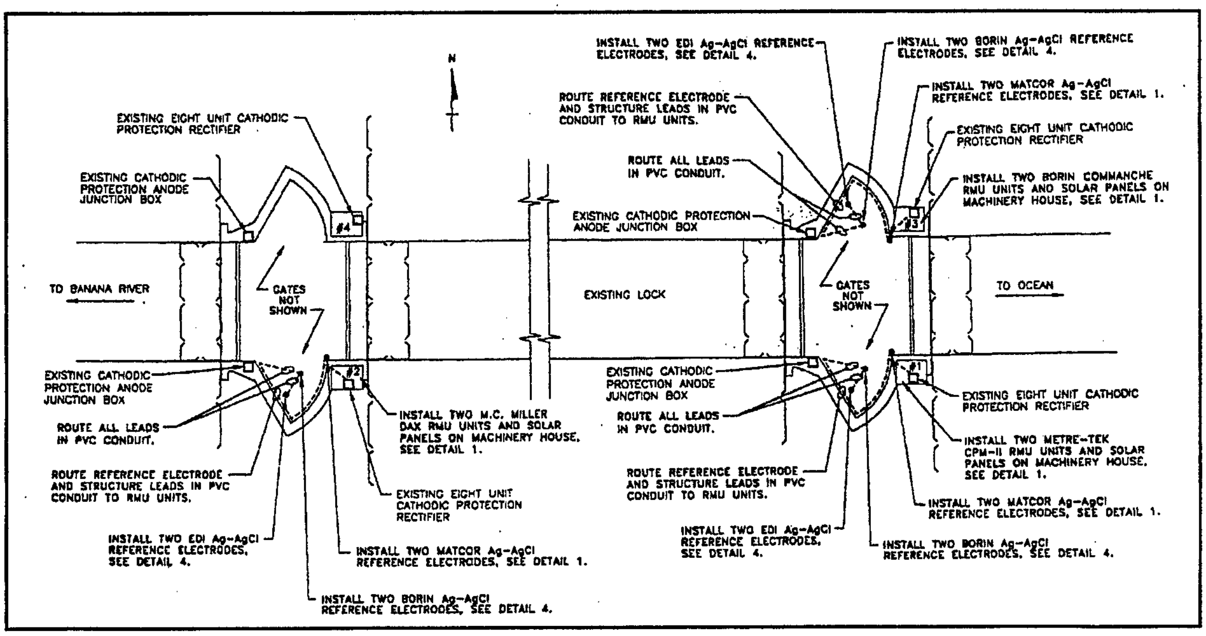

Figure 4. Original layout planned for Canaveral Lock test site.

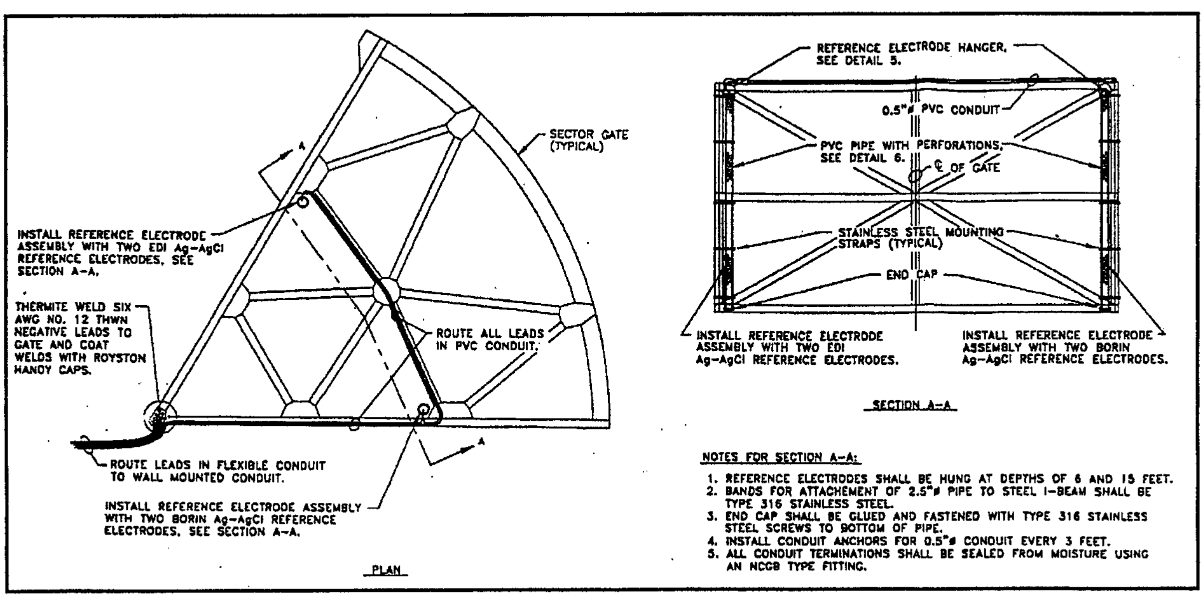

Figure 5. Original reference cell mounting detail.

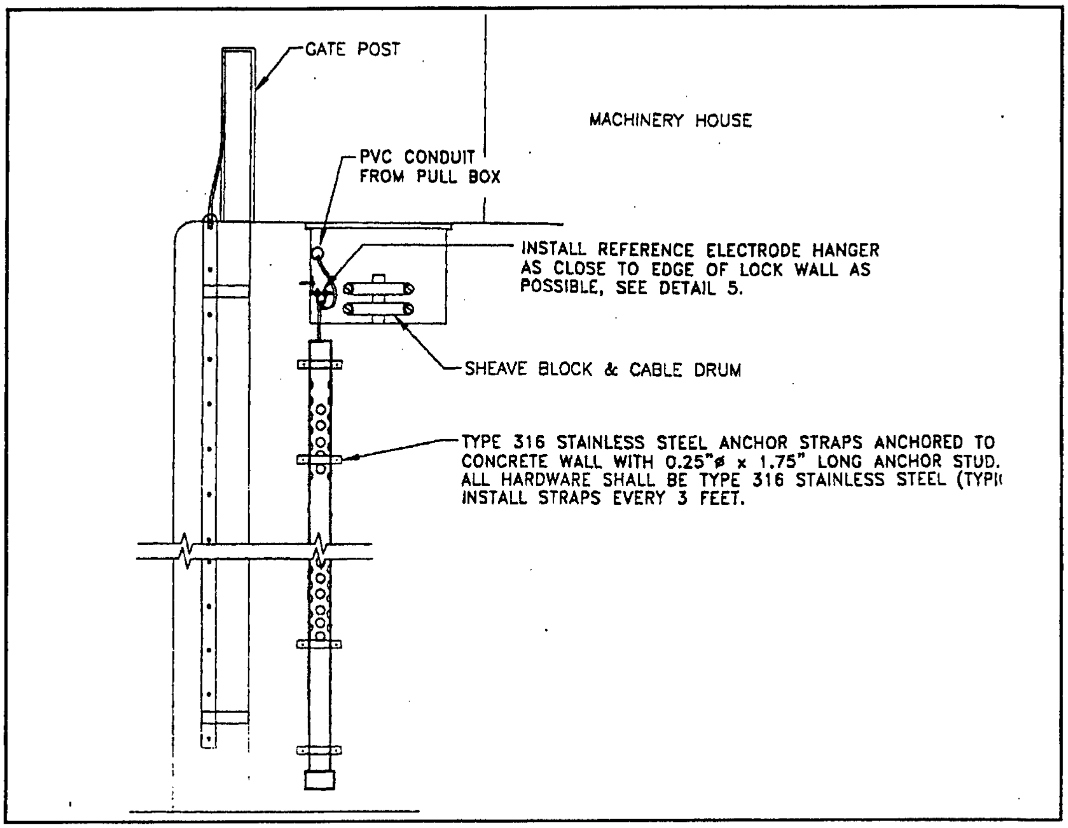

Figure 6. Original reference cell shield.

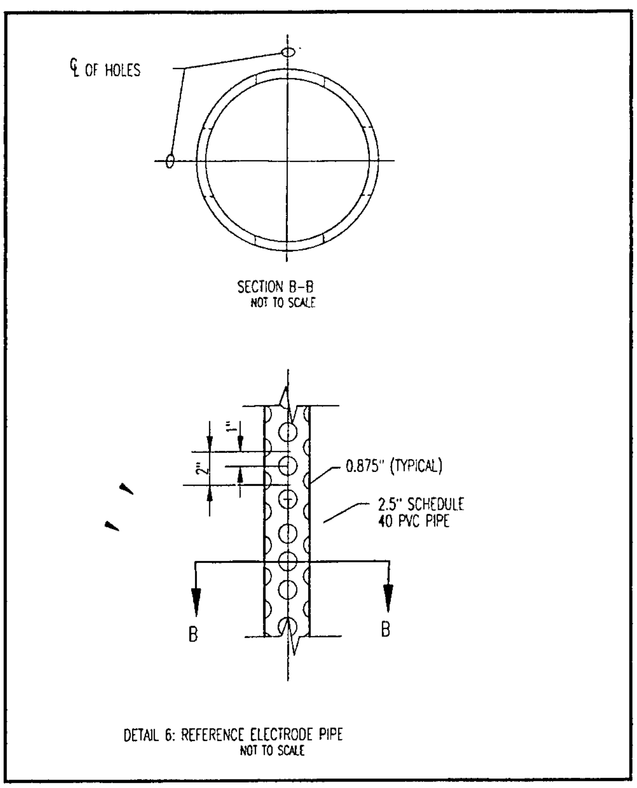

Figure 7. Original reference cell shield detail.

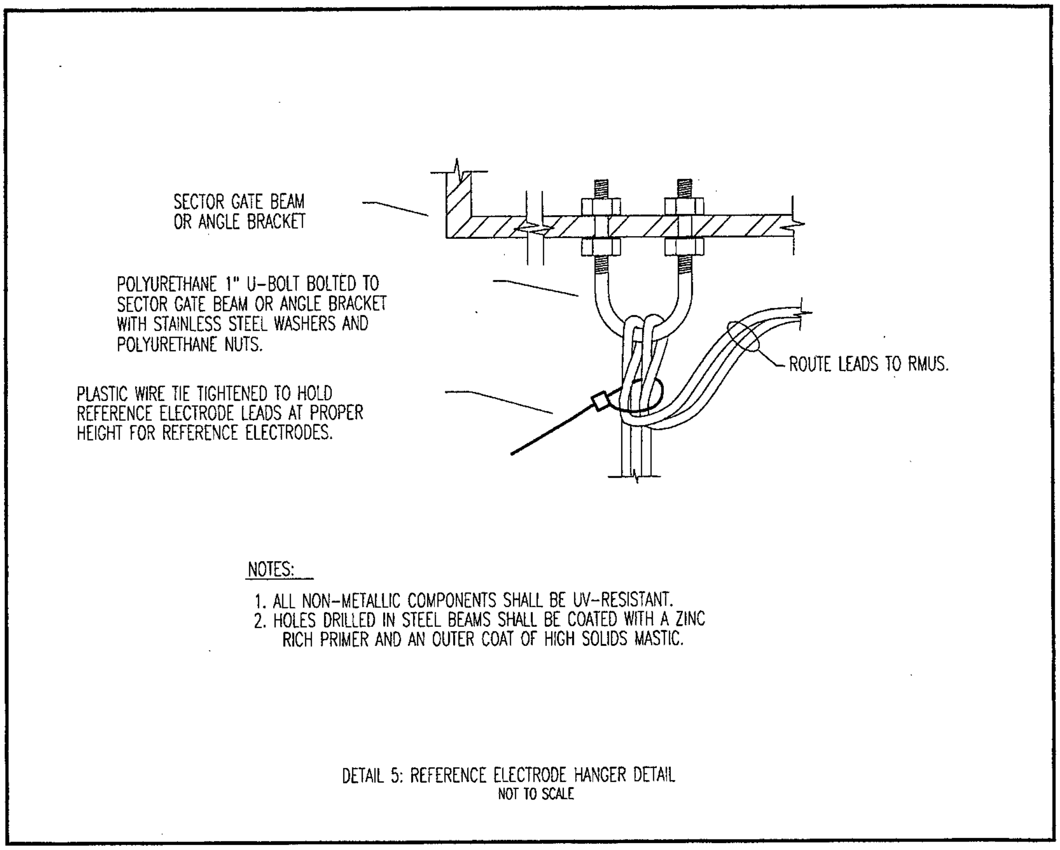

Figure 8. Reference cell hanger detail.

Modified Site Design

The next step was to find out how much it would cost to mount and wire the RMUs and reference cells according to the original design. Jacksonville District engineers indicated that they did not have the personnel available to perform the installation, so CERL contacted four local electrical contractors that they recommended. Only one contractor, Loftus Electric of Melbourne, FL, indicated that they had the knowledge and capabilities required for the job. Loftus had previously performed work at Canaveral Lock and had installed part of the existing CP system.

Several difficulties arose during the contracting process, and these are described in the following paragraphs. The net result was a delay of over 3 months from the time CERL began discussions with Loftus to the time a contract was awarded to them.

Overall layout

The original overall layout was found to be prohibitively expensive. The costs of labor and brackets required to mount electrical conduit within the lock chambers were much higher than anticipated. To reduce the cost, it was decided to restrict the tests to two gates only. The ocean-side gates (Gates 1 and 3) were selected so that the units would be subjected to the water with the highest salinity. The test site layout was revised accordingly, and is shown in Figure 9. This layout placed both Metretek CPM-II units and the solar-powered M.C. Miller DAX unit on Gate 1, and both Borin Comanche units and the AC-powered M.C. Miller unit on Gate 3.

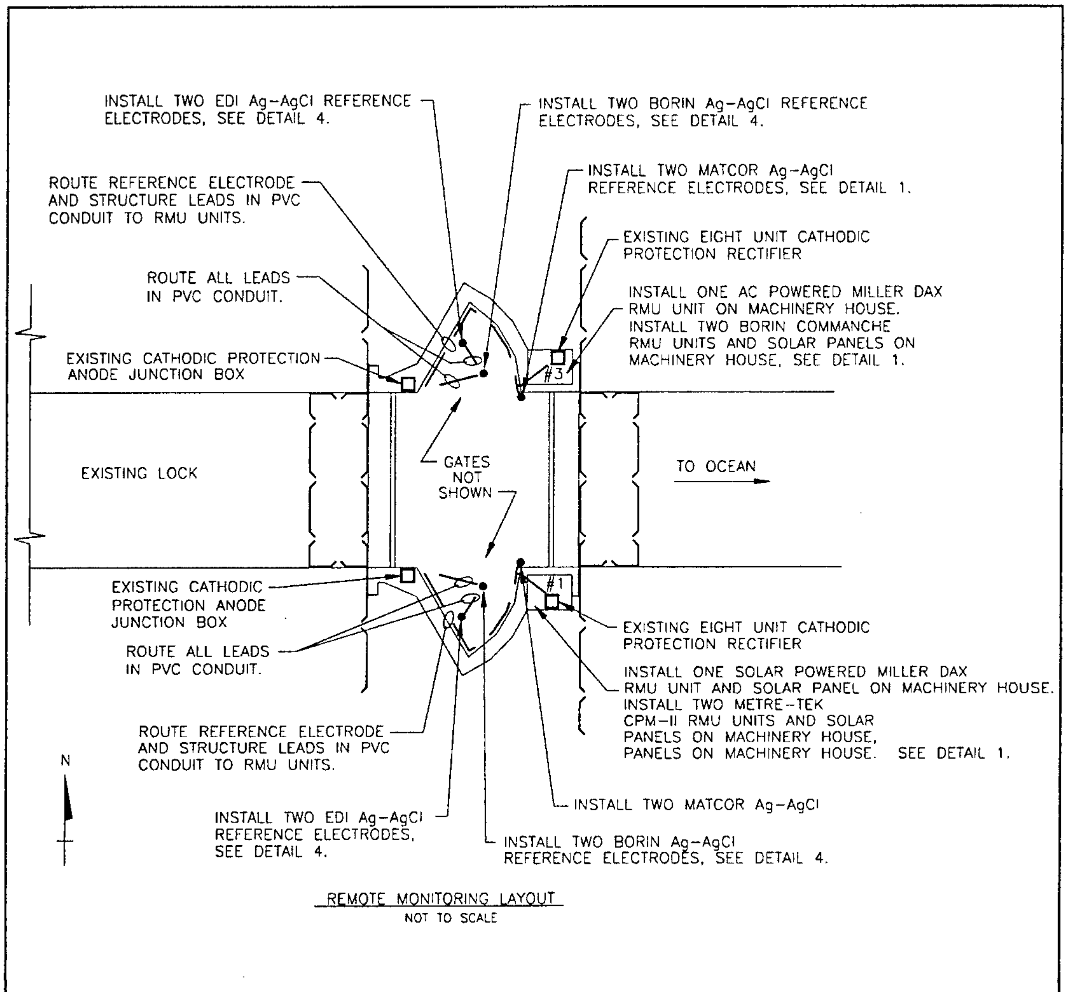

Figure 9. Final test site layout.

Reference cell shields and mounting

In the original design, the reference cell shields were attached to the structure by brackets that were spaced 3 ft apart along the entire length of the shield. Several of the brackets would have been underwater, however, and installing them would have either required that the locks be drained, or that certified divers to be hired to do the work. Both alternatives were prohibitively expensive.

Another problem with the reference cell holders was that their end caps were solid and would not let silt from the murky water escape.

The reference cell holders were redesigned to take care of these problems. First, the mounting brackets were spaced 1 ft apart and were only placed above the low tide line. The polyvinyl chloride (PVC) pipe was changed from a Schedule 40 pipe to a Schedule 80 pipe for additional strength. The dimensions and spacing of the perforations in the pipe were changed to maintain strength. A 0.75 in. diameter hole was placed in the end cap to ensure silt drainage. The as-built design of the reference cell holders is shown in Figure 10 and Figure 11.

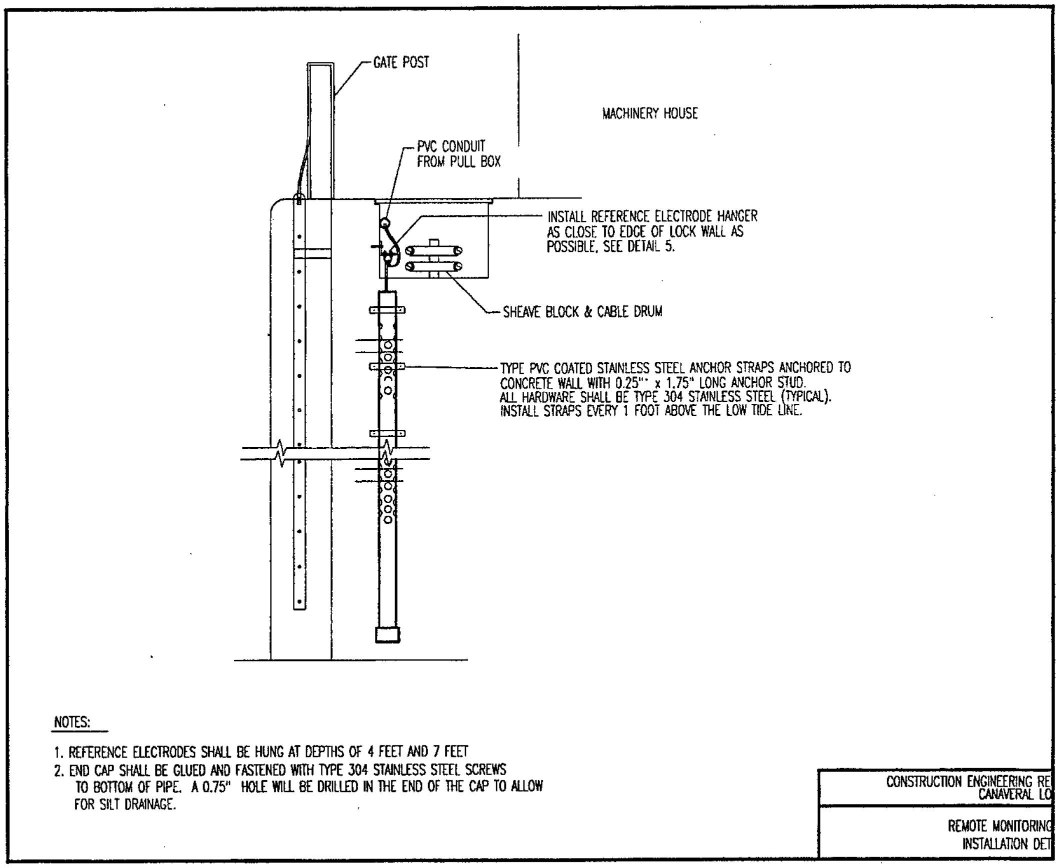

Figure 10. As-built reference cell shield.

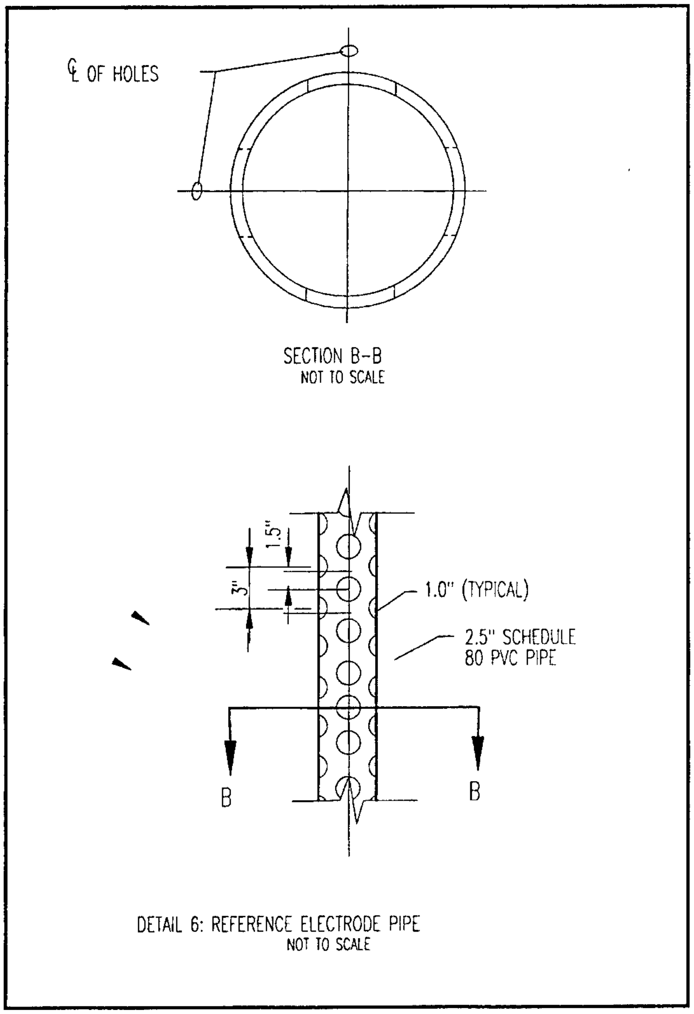

Figure 11. As-built reference cell shield detail.

Reference cell locations

The original design placed two of the reference cells and holders in locations where they would interfere with the mechanisms used to open and close the gates, so they had to be moved. It was difficult to determine where to place them since the contractor had not taken photos of the site during the November site visit. It was eventually decided to place the reference cells behind a ladder on the lock wall, as shown in Figure 12.

Figure 12. Reference cell mounted behind ladder.

Materials

The original site design specified that all of the hardware, including screws and mounting brackets for the electrical conduit, were to be made of Type 316 stainless steel. Loftus Electric found that the required amount of Type 316 stainless steel was not readily available locally. It took them 3 weeks to locate a source and obtain a price quotation. The price was too high for the available budget. Price quotations were obtained for coated steel brackets and for 304 stainless steel brackets. The 304 stainless steel brackets were less expensive, so they were implemented in the design.

Thermite welds were specified in the design. Loftus Electric had difficulty locating the required materials and apparently did not recognize that "Cadweld" is a type of thermite weld. They also had difficulty locating the correct size mold to accommodate the 12 gauge wire leads. The confusion and supply problems with thermite welds led to another two-week delay.

Contract Award

A contract was awarded to Loftus Electric on 22 May 2000 to mount and wire the RMUs and reference cells according to the revised design discussed above.

Equipment Specifications and Procurement

During the same time period that discussions were in progress with Loftus Electric, the ordering specifications for the RMUs were being developed based on the configuration and specifications of the CP equipment in place at the Canaveral site. Two RMUs were ordered from each of the manufacturers according to the following specifications:

1. All units shall be able to monitor the following:
   a. three structure-to-electrode potentials (0 to 2 volts DC)
   b. rectifier DC output voltage (0 to 24 volts DC)
   c. rectifier DC output current (0 to 4 amperes measured on a 0.01 ohm shunt)
   d. presence of the rectifier 120 volt AC power.

2. All units shall be able to interrupt the rectifier current at a capacity of 4 amperes maximum.

3. All units shall be capable of cellular phone communications. The cellular phone communication shall be provided by the RMU manufacturer to assure full compatibility of the cellular system with the operating requirements of the remote monitoring unit. Each remote monitoring unit shall be provided with an independent cellular phone connection.

4. One of the units shall be solar powered. The RMU manufacturer shall provide an independent solar panel for mounting on the roof of the building where the RMU is installed. The solar panel shall be sized and provided by the RMU manufacturer to assure full compatibility of the solar power system for the operating current requirements of the remote monitoring unit.

5. The manufacturer shall provide weatherproof locking enclosures for mounting all equipment outdoors.

6. The manufacturer shall provide software with the following capabilities:
   a. ability to measure three structure-to-reference electrode potentials ("on" and "instant off")
   b. ability to measure rectifier DC output voltage
   c. ability to measure rectifier DC output current
   d. ability to monitor presence of rectifier 120 volt AC power
   e. ability to call and interrogate individual RMUs for the above data
   f. ability to call and simultaneously interrogate two individual RMUs for the above data
   g. ability to independently monitor above data onsite at least four times daily and to call (alarm) an independent computer in the event of a data reading outside of preset parameters.

The costs for the AC-powered RMUs are shown in Table 7 and costs for solar-powered RMUs are shown in Table 8. Permanent silver / silver chloride reference cells were ordered from the three manufacturers listed previously. Costs are shown in Table 9.

Table 7. Cost of AC-powered RMU systems.

Item	Borin Comanche	M.C. Miller DAX	Metretek CPM-II
Base unit	$2,850.00	$1,900.00	$1,875.00
Cellular phone transceiver	$720.00	Included in base unit	Included in base unit
Modem for master computer	$140.00	$140.00	$1240.00
Power Interrupter/ Relay	$7.00*	$7.00*	$556.00
TOTAL	$3,717.00	$2,047.00	$3,671.00

* This is the cost of the relay that was purchased from the local electronics store near the Canaveral test site. The cost of the manufacturer-supplied relay that is designed for long-term service may be higher.

Table 8. Cost of solar powered RMU systems.

Item	Borin Comanche	M.C. Miller DAX	Metretek CPM-II
Base unit	$2,850.00	$1,900.00	$1,875.00
Cellular phone transceiver	$720.00	Included in base unit	Included in base unit
Modem for master computer	$140.00	$140.00	$1,240.00
Power Interrupter/ Relay	$7.00*	$7.00*	$556.00
Solar power equipment	$2495.00	$350.00	$2081.00
TOTAL	$6,205.00	$2,397.00	$5,752.00

* This is the cost of the relay that was purchased from the local electronics store near the Canaveral test site. The cost of the manufacturer-supplied relay that is designed for long-term service may be higher.

Table 9. Cost of permanent reference cells.

Make and Model	Cost
Matcor PRC-AGS	$225.00
Electrochemical Devices IMA-AGG-LWw050	$459.00
Borin Stealth	$170.00

Equipment Received for Testing

Manufacture and shipping of the RMUs took approximately 2 to 4 months from the time that complete specifications were provided to the manufacturers. The Borin Comanche equipment received at CERL is shown in Figure 13 through Figure 16. The M.C. Miller DAX equipment received at CERL is shown in Figure 17 and Figure 18. The Metretek CPM-II equipment received at CERL is shown in Figure 19 through Figure 21. The permanent reference cells received from the various manufacturers are shown in Figure 22 through Figure 23.

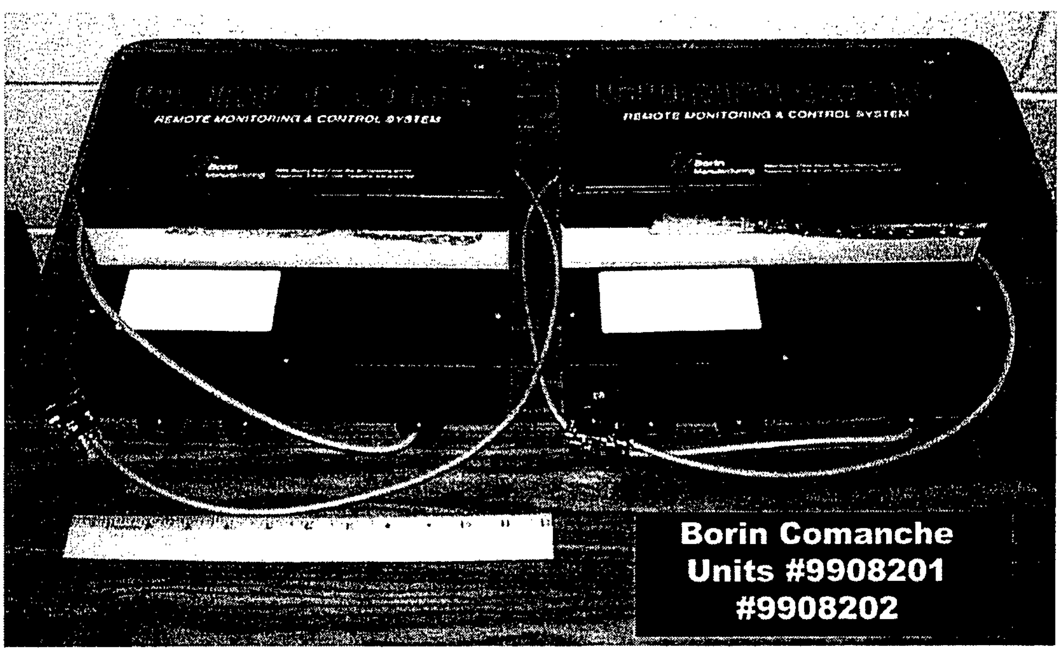

Figure 13. Borin Comanche RMUs.

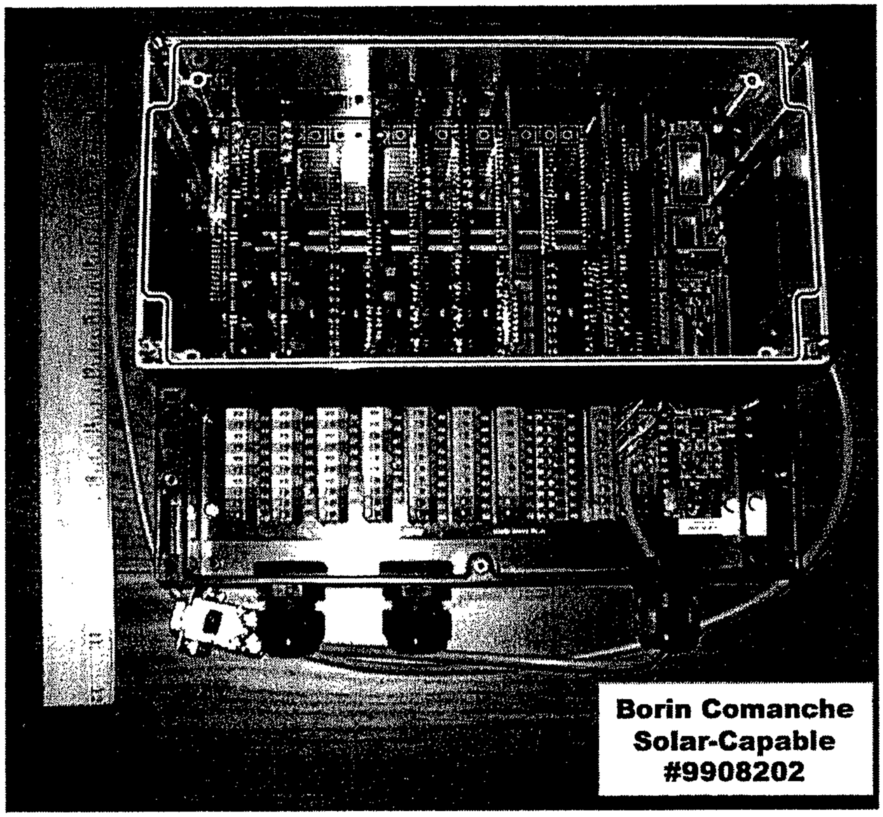

Figure 14. Inside of solar-powered Borin Comanche RMU.

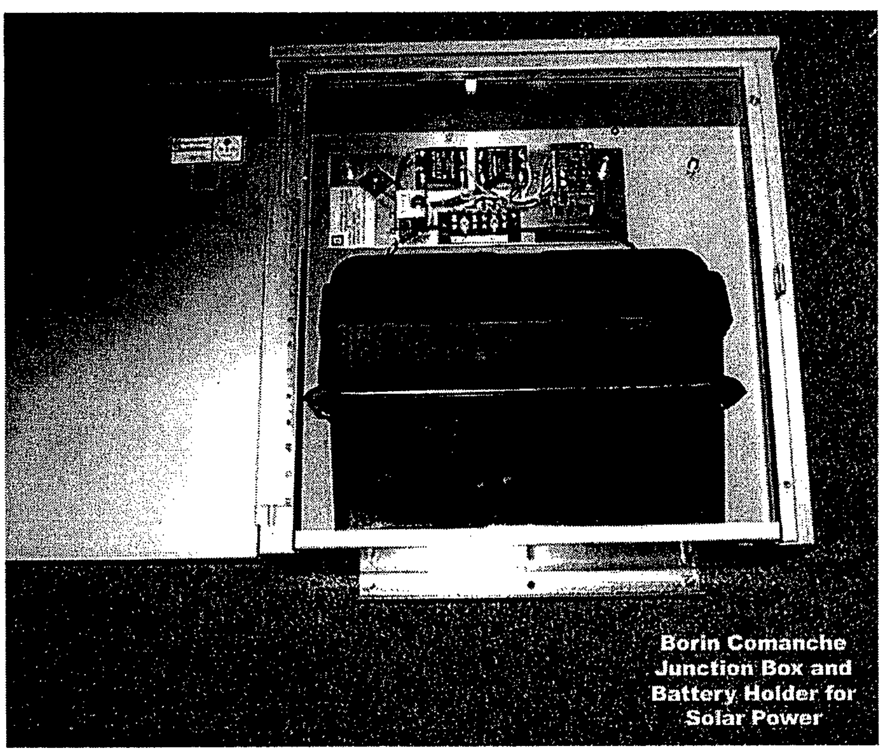

Figure 15. Borin Comanche junction box for solar-powered RMU.

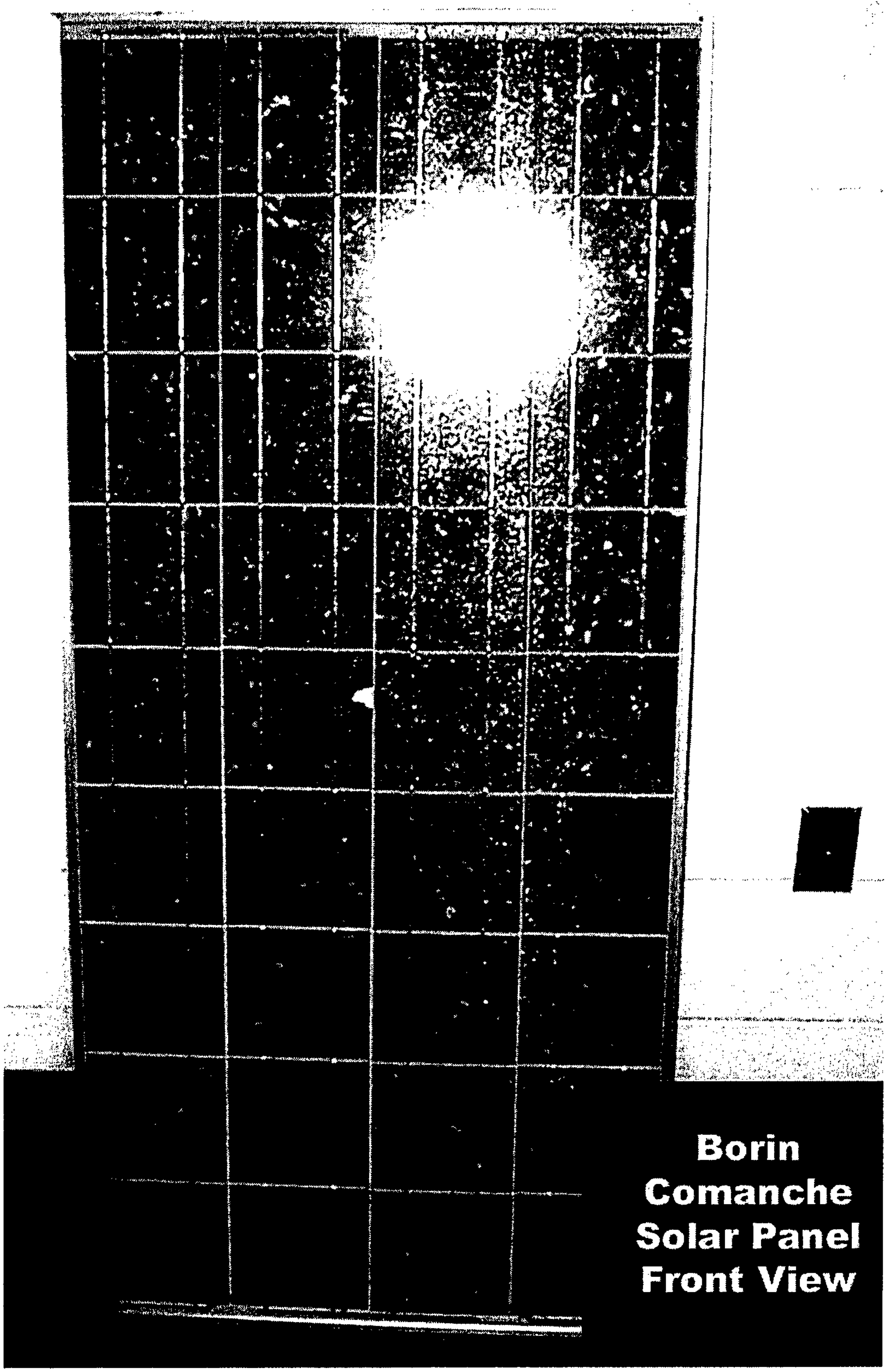

Figure 16. Borin Comanche solar panel.

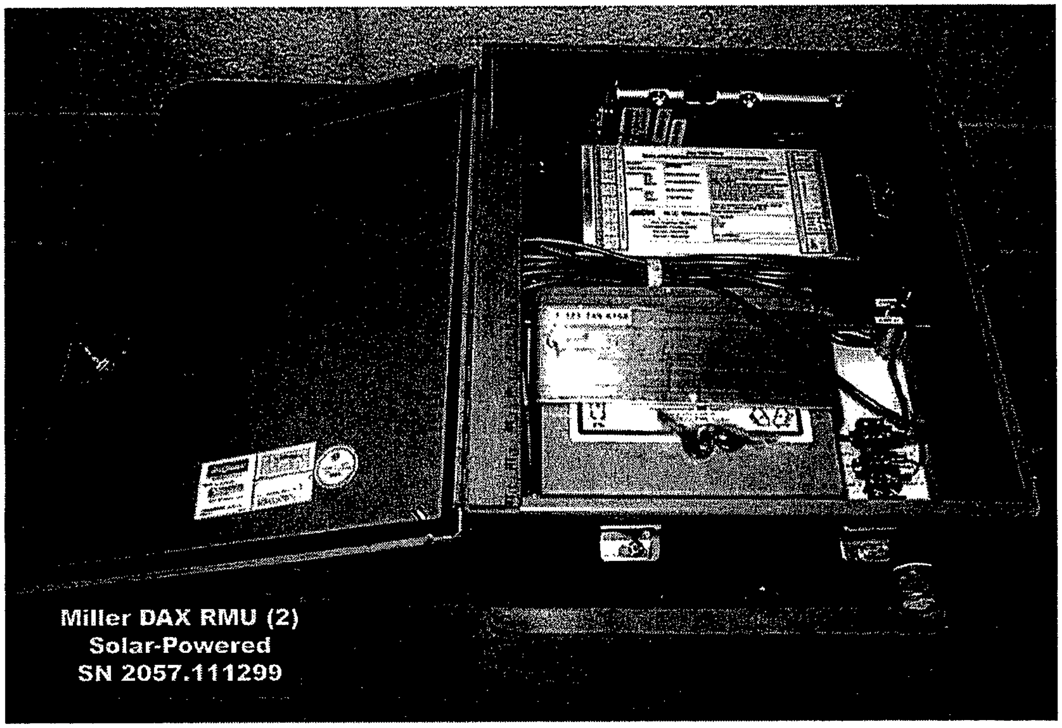

Figure 17. Inside of solar-powered M.C. Miller DAX RMU.

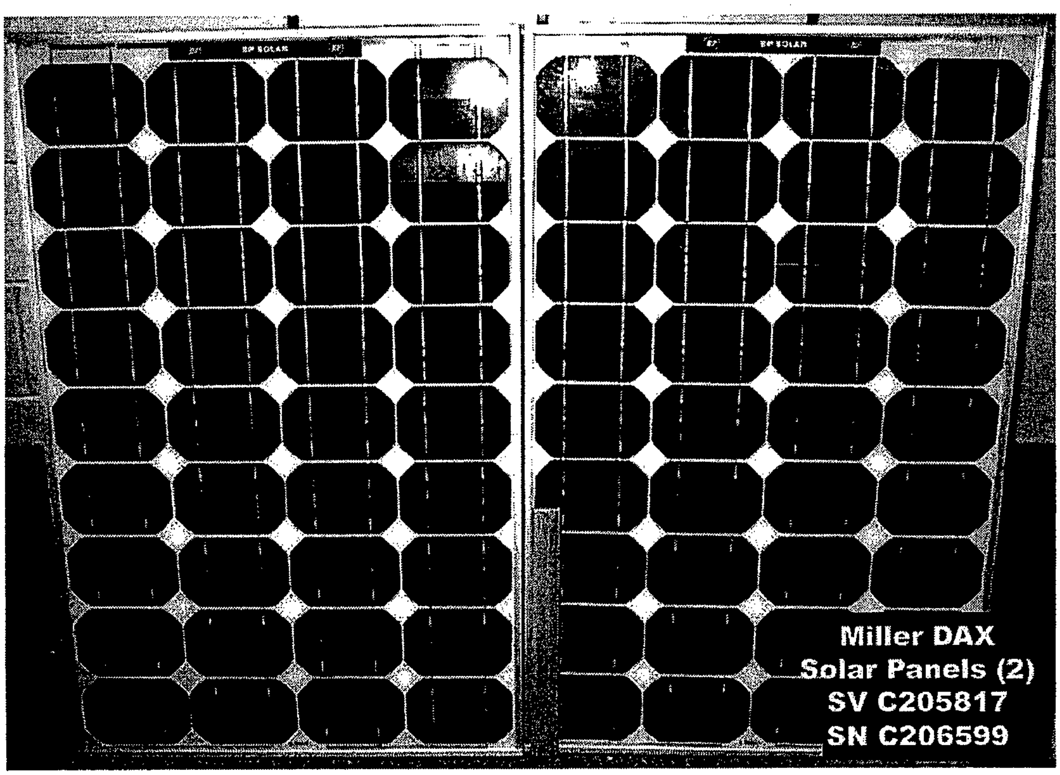

Figure 18. Solar panel for M.C. Miller DAX.

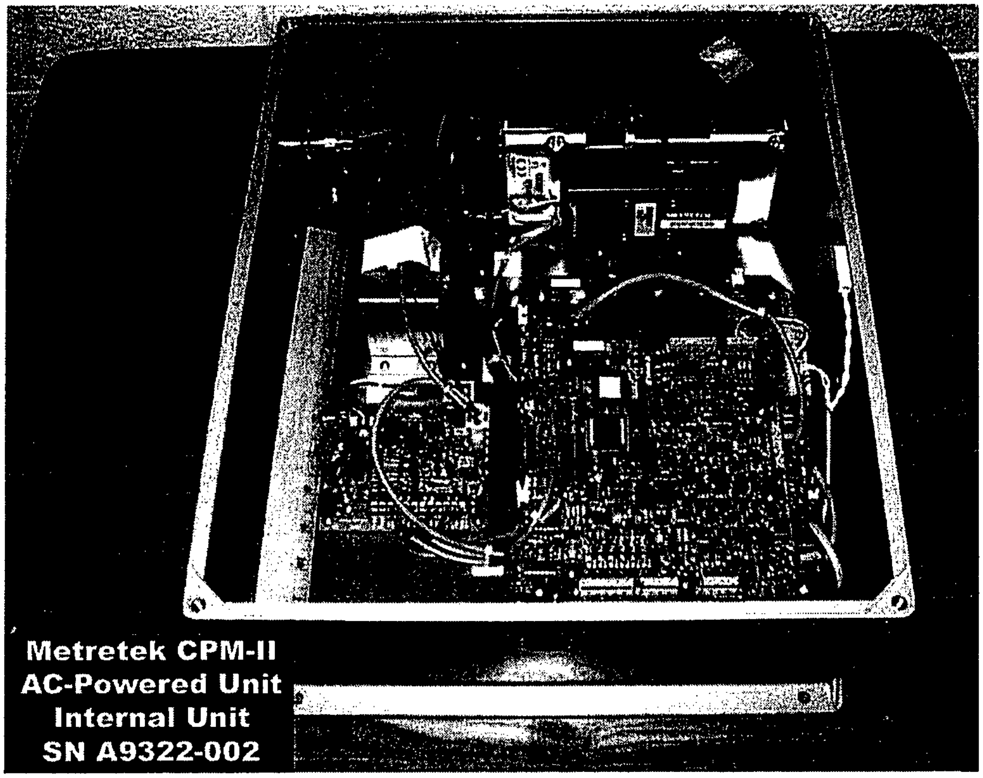

Figure 19. Inside of Metretek CPM-II RMU.

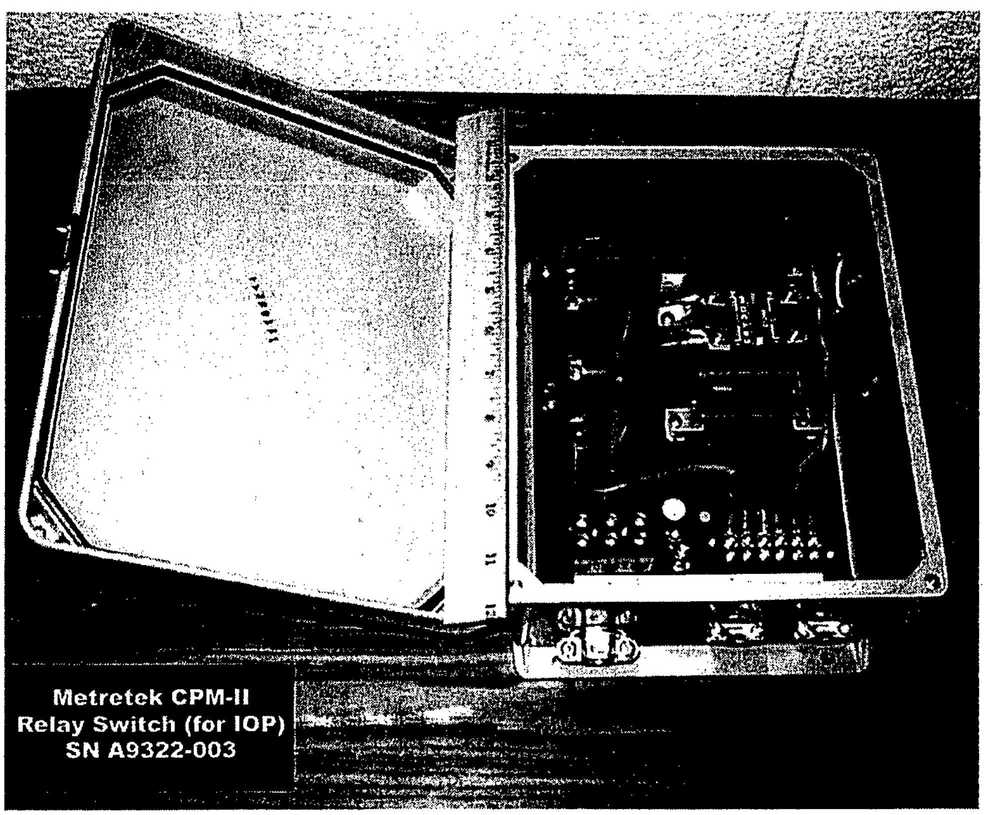

Figure 20. Relay switch for IOP readings supplied with Metretek CPM-II.

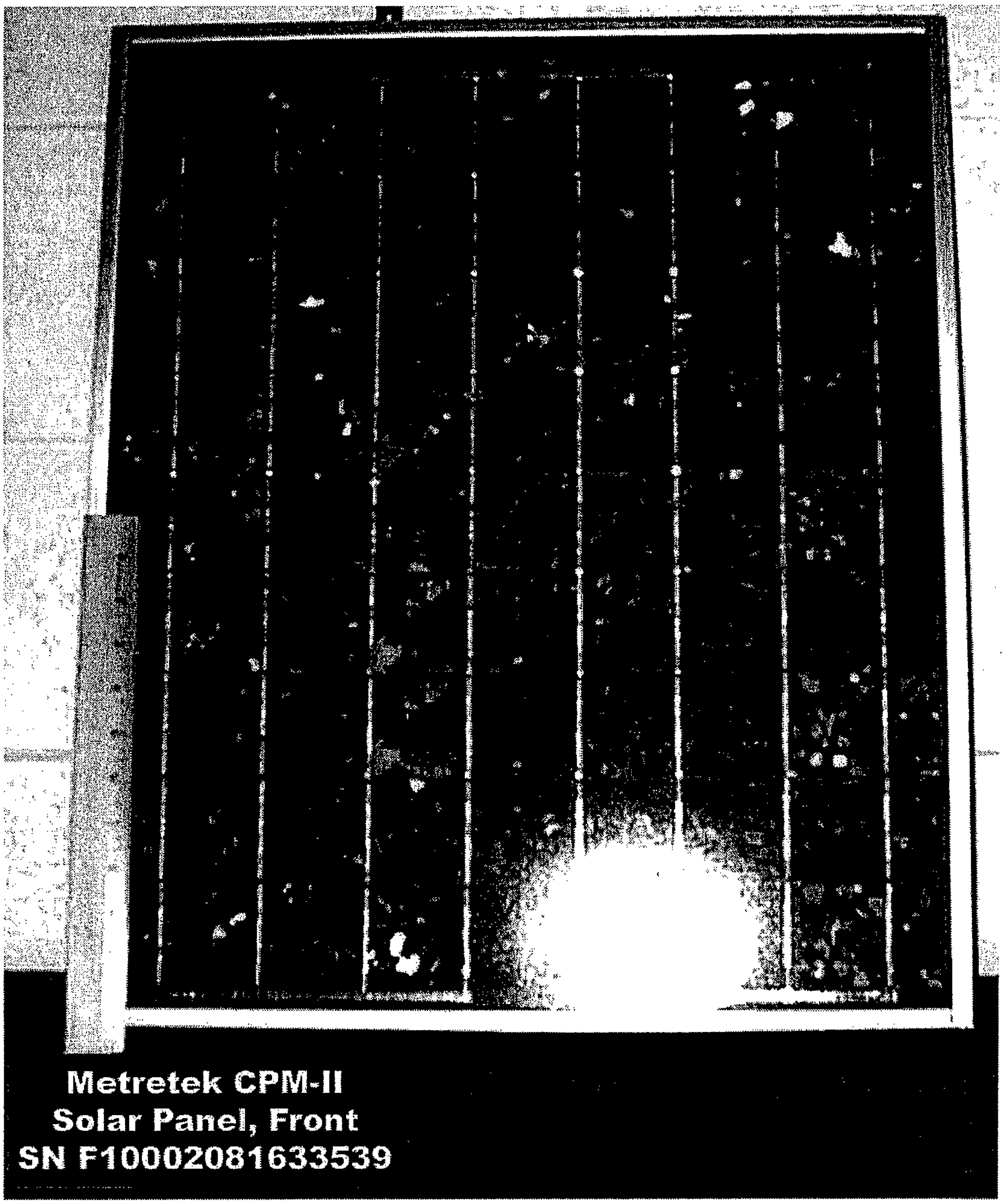

Figure 21. Solar panel for Metretek RMU.

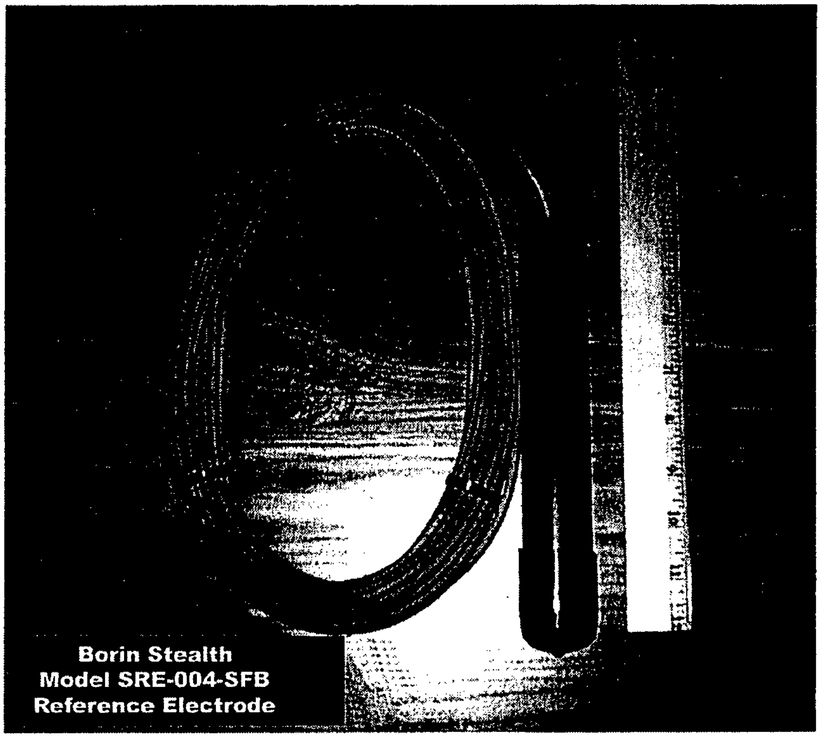

Figure 22. Borin Stealth permanent reference electrode.

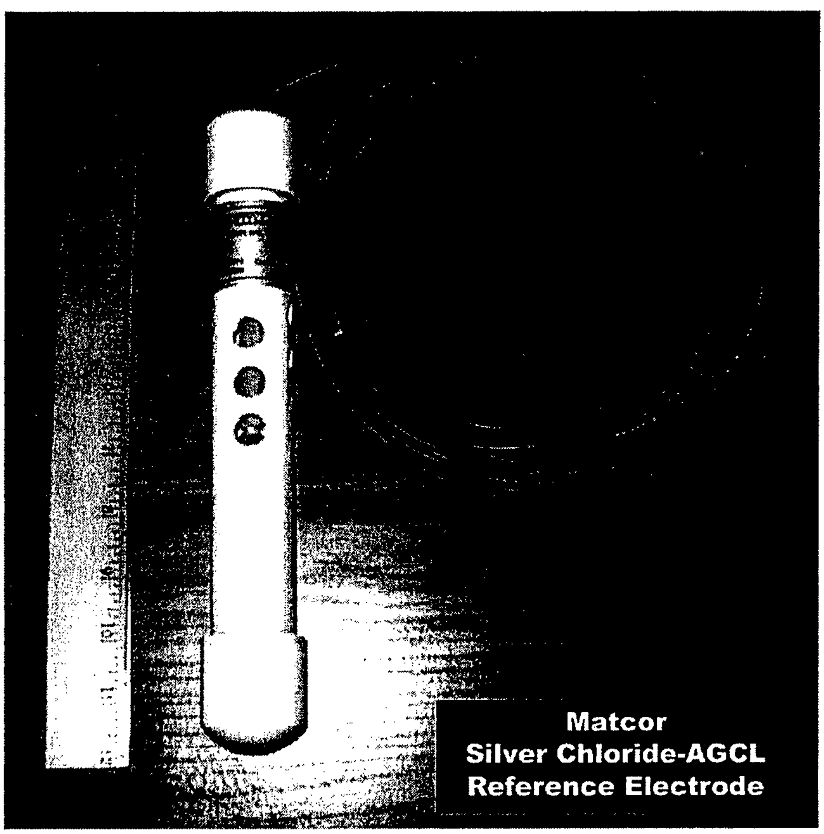

Figure 23. Matcor permanent reference electrode.

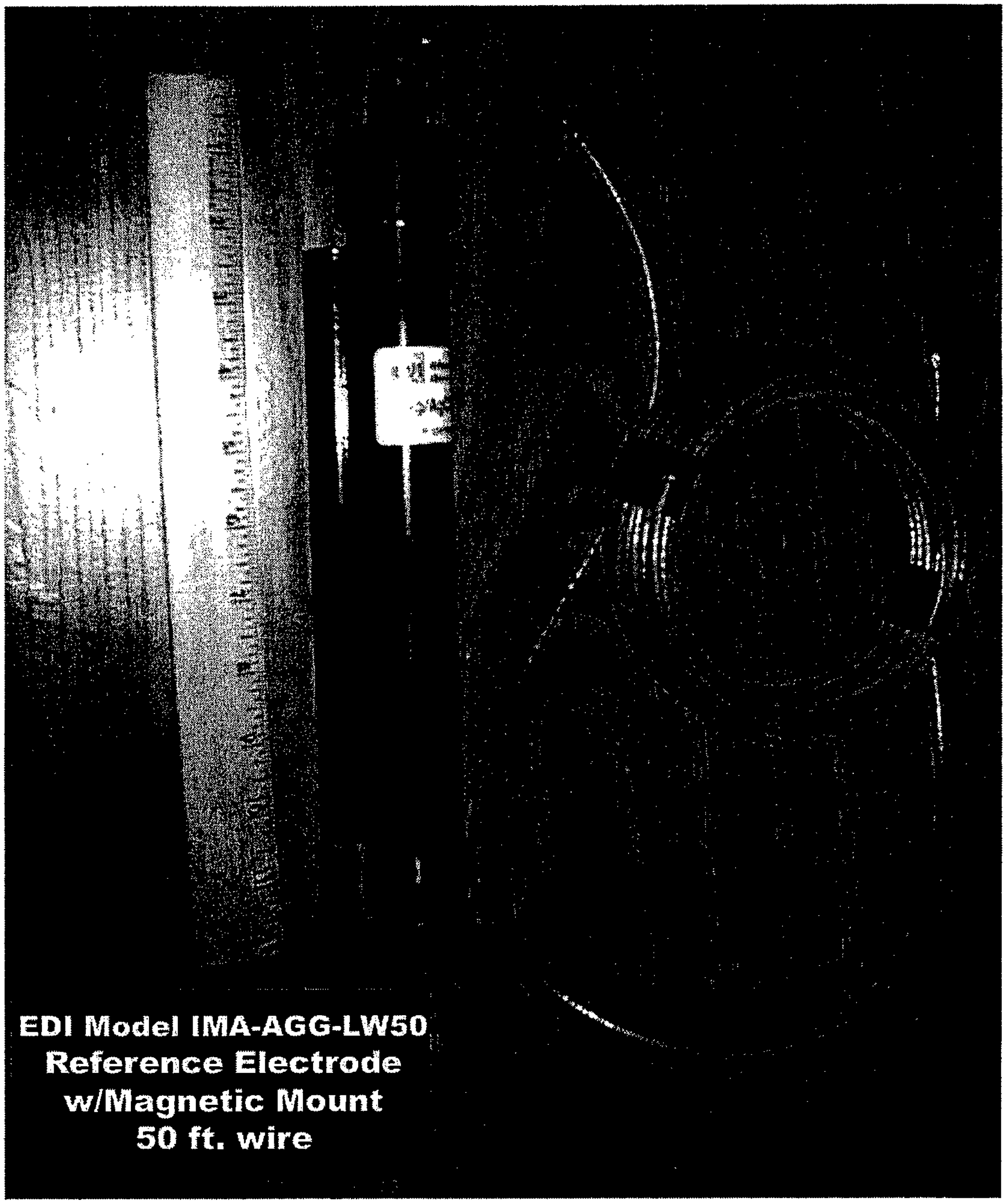

Figure 24. EDI permanent reference electrode, showing magnet (left) to help hold it in place on the steel gate surface.

In spite of efforts to make sure that everything was covered in the equipment specifications, there were problems. The problems could be remedied, but most of them resulted in delays of several weeks, and some of them resulted in additional costs.

M.C. Miller and Borin Manufacturing did not provide the relay switches that are required for IOP readings. The power supply for the AC-powered Borin unit was also missing from the original shipment. This was not discovered until the RMUs had been shipped to the Canaveral site and installation was underway.

It was found that the Borin Comanche units required a separate transceiver to make outgoing cellular phone calls. The cost of the transceiver had not been included in the original contract, and this added significant cost and a 3-week delay.

Another hardware requirement was that the manufacturers provide one solar-powered unit. This requirement caused some confusion, and lengthy delays resulted in some cases. Metretek's original shipment included two AC-powered units, but not a solar-powered unit. Metretek was notified about this problem, and one of the units was sent back to them for reconfiguring. This took approximately 6 weeks.

The transceivers supplied for the solar Borin Comanche unit were AC-powered and there was no convenient way to convert them to solar power. The RMU itself, however, was solar powered.

Some of the units were not supplied with weatherproof locking enclosures even though this was explicitly required in the specifications.

In general, it seems likely that many of the equipment problems described above could have been avoided by making the manufacturer responsible for a complete turnkey installation, as suggested on page 91 (Chapter 6).

Test Site Installation

Loftus Electric's statement of work required them to review the manufacturer-provided installation instructions, mount and wire the RMUs and reference cells, and install the required electrical conduit. This included mounting several hundred feet of conduit within the lock chambers. The contractors estimated that they would need two to three weeks to complete the work.

June 2000 Site Visit

Loftus Electric began work in late May 2000. They stated that they were almost finished with the work in mid-June, so CERL scheduled a site visit to inspect the installation during the last week of June. However, the work was not as complete as the contractors had reported. The conduit and wires had been mounted on the lock walls, but much of the wiring had not been completed. At the time of the site visit, almost thirty components were not yet installed, including important ones such as transceivers and antennae. The contractors worked throughout the CERL site visit (Figure 25).

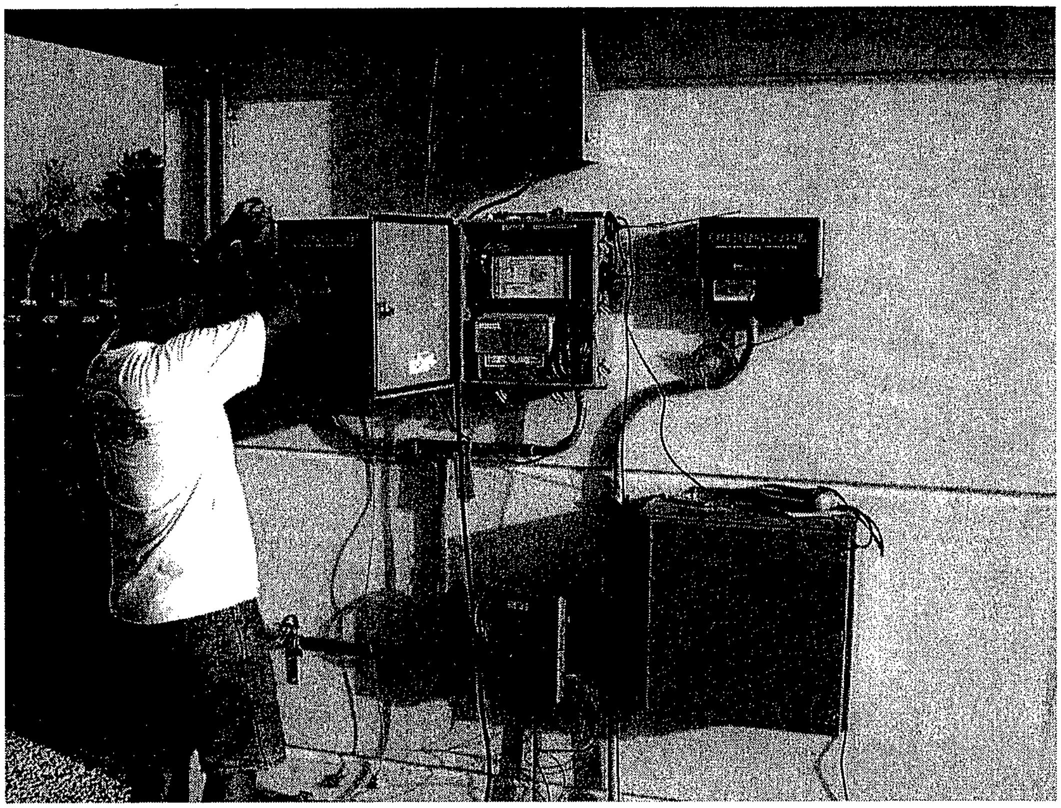

Figure 25. Contractor working on RMU wiring during June 2000 site visit.

One of the main problems with the installation phase was that the documentation provided by the RMU manufacturers was not understood by the electricians. The contractors also stated that the work had been slowed by the opening and closing of the locks to allow traffic flow.

As noted above, relay switches for the Miller and Borin units and the power supply for the AC-powered Borin unit were missing from the RMU shipments. To address this problem, relays were purchased from a local electronics store, and the electrical contractors were given guidance for installing them. Borin was notified of the power supply problem and the company shipped one to the site immediately by overnight mail.

There were some difficulties and confusion in connecting the units to measure rectifier voltage and current outputs. As noted previously, the rectifiers at Canaveral Lock contain eight individual circuits. Each circuit has its own positive output terminal. There is a common negative terminal for all circuits. Each circuit has its own shunt for current measurement, but there is no shunt in either the positive or negative circuit that allows measurement of the total current output of the rectifier. Measurement of the total current output of the rectifier would have required the installation of a shunt between the negative return lead and the lead connected to the common negative terminal in the rectifier.

For the purposes of this evaluation, one circuit on each rectifier was selected for monitoring. The circuits with the highest current output were chosen. Circuit 6 was selected at Machine House 1 and Circuit 8 was selected at Machine House 3. The electricians were given instructions on where to make the connections. Rectifier outputs were measured during the site visit using a Fluke 87 digital multimeter, and they are shown in Table 10 and Table 11.

Table 10. Rectifier outputs at Machine House 1 (27 June 2000).

Circuit Number	Voltage Output of Circuit (V)	Voltage Measured Across Shunt (mV)	Calculated Current Output of Circuit (mA)*
1	2.516	5.2	520
2	2.595	5.5	550
3	3.246	5.7	570
4	2.927	5.5	550
5	3.135	5.2	520
6	2.756	5.6	560
7	2.564	5.6	560
8	2.802	5.5	550

* Current outputs were calculated by measuring the voltage drop across the rectifier shunt, then using the shunt rating of 50 millivolts = 5 Amps.

Table 11. Rectifier outputs at Machine House 3 (27 June 2000).

Circuit Number	Voltage Output of Circuit (V)	Voltage Measured Across Shunt (mV)	Calculated Current Output of Circuit (mA)*
1	1.925	0.4	40
2	1.925	0.7	70
3	2.038	0.7	70
4	2.191	0.7	70
5	2.586	3.2	320
6	2.199	3.2	320
7	2.200	3.2	320
8	2.438	5.6	560

* Current outputs were calculated by measuring the voltage drop across the rectifier shunt, then using the shunt rating of 50 millivolts = 5 Amps.

It was difficult to obtain a stable current output reading on several of the rectifier circuits; the readings tended to jump around between zero and the values recorded in the tables. This phenomenon is a typical indication of intermittent short circuits in a CP system. Structure on-potentials were measured on Gates 1 and 3. The on-potential on Gate 1 ranged from –0.646 V to –0.663 V versus a silver / silver chloride reference cell. The on-potential on Gate 3 ranged from –0.606 V to –0.647 V versus a silver / silver chloride reference cell. Evaluation against NACE International CP criteria (NACE International 1996) indicates that neither gate was adequately protected from corrosion at the time of the survey. Lock personnel were advised of the observed problems, and a detailed CP system survey was recommended to accurately diagnose and correct the problem.

August 2000 Site Visit

The equipment installation still had not been completed by late July, so CERL made another site visit during the week of 7 August 2000. A number of problems were found and corrected during this site visit. First, the relay was not wired properly for the Borin Comanche AC-powered unit despite direct instruction and wiring diagrams provided during the June site visit. Also, the relay was not provided with any power, and in fact no power supply was installed on the unit. .

Second, several channels were burned out in the Metretek units because the polarities had been reversed and the shunts had been wired improperly. Polarity also had been reversed on the solar input to the Miller solar-powered DAX, resulting in a complete power drain of its battery. The fuse was blown on the AC-powered DAX unit, and the unit had apparently been disassembled and reassembled improperly, evidently causing it to malfunction. Overall, the wiring was difficult to follow because most wires were not tagged at their ends or junctions.

There were several problems with workmanship. Loftus had left exposed holes in many of the equipment cases, allowing salt-laden moisture and condensation to get into several components. Seals were not provided, and some had even been removed from the solar-powered Comanche and the equipment box containing the outlet, transceivers, transceiver power supplies, and the power supply adapter for the AC-powered Comanche. Conduit was not provided for several of the connecting wires between the units. For example, the RS-232 serial cable from the Comanche to the transceiver box was exposed. The relay switch for the AC-powered Comanche was secured to the side of the equipment cases with two-sided tape. This tape did not hold up under the high heat and humidity, and the relay switches were hanging from their wires in the equipment cases.

Representatives from all three RMU manufacturers visited the site during the August visit to assist CERL personnel in completing the configuration of the RMUs. The manufacturers reviewed and approved the wiring and setup. At the end of the visit, all of the units had been connected and were functioning. Only a few minor tasks remained for Loftus Electric to complete the job. CERL began logging data remotely from Champaign, IL, on 15 August 2000.

September 2000 Site Visit

The last site visit for this project was performed in late September 2000. Loftus Electric had completed the site work by this time. The completed site is shown in Figures 26 and 27. Detailed photos and diagrams are shown in the Appendix.

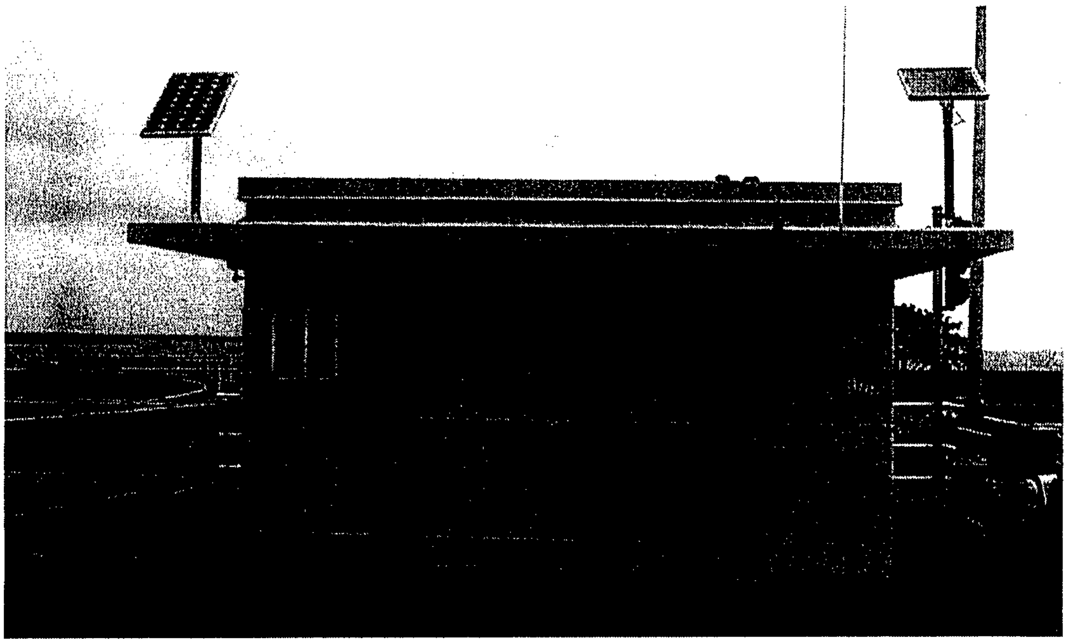

Figure 26. Overview of equipment installed at Machine House 1.

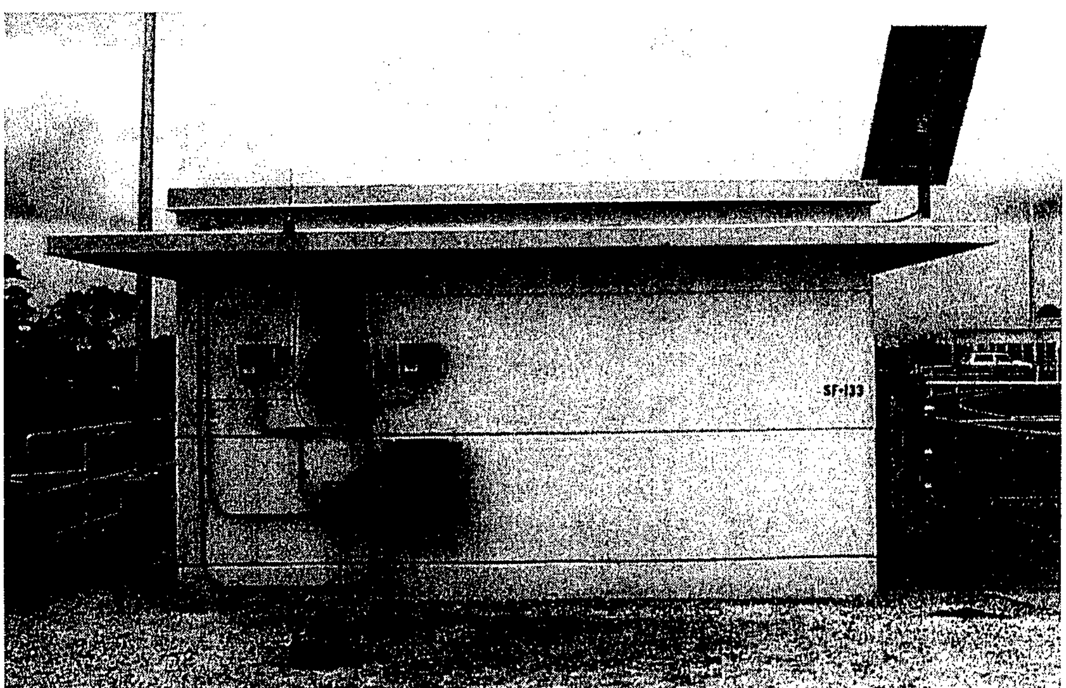

Figure 27. Overview of equipment installed at Machine House 3.

5 Evaluation Procedure and Results

An eight-step procedure was developed for evaluation of the RMU systems. The evaluation focused on factors including field installation, hardware performance and reliability, software performance, and quality of hardware and software manuals. The steps are described in order, and the results are documented for the Borin Comanche, M.C. Miller DAX, and the Metretek CPM-II.

Step 1: Evaluation of Hardware Manuals

The hardware manuals were reviewed and evaluated in terms of clarity, completeness, and conciseness in documenting the preparation and procedures necessary for installing the RMU hardware. A good manual should be well organized and easy to follow. System components and their purposes should be clearly explained, and tools and equipment required to install the systems should be identified. Installation sequencing should be logical, complete, and understandable, and any required post-installation field-testing should be explained.

Results: Borin Comanche

RMU manual

The RMU manual provided with the Borin Comanche was mostly complete, but it was difficult to understand. The main reason for this is that the Comanche can be used for a wide variety of data acquisition and control applications; CP monitoring is only one of the many possible applications supported. The RMU manual covered the general application of the Comanche and did not provide very much information specific to CP. Therefore, the reader needed to have a detailed understanding of the required configuration in order to perform the installation procedures.

Wiring diagrams were not provided. There were no instructions for configuring the relay switches that are needed to measure IOP.

One useful feature is that the manual was available online in Portable Document Format (PDF), allowing users to download the latest version of the manual as changes occur.

A more complete explanation of related difficulties is included in the hardware installation section.

Cellular modem manual

The manuals for the transceiver (used for the cellular modem) were difficult to apply to CP systems. The wiring diagram included in the transceiver manual was for an automobile application. There were no instructions for using the transceivers in a CP application. As a result, the transceiver installation requires an expert user familiar with configuring digital modems.

Instructions for solar power system and accessories

The solar power system instructions were shipped directly from the solar panel manufacturer and contained adequate wiring diagrams for the battery equipment case and the solar panel. The instructions for the solar panel and power system were complete and descriptive.

It was not possible to power the cellular phone transceiver with solar power, so instructions for this were not provided.

Results: M.C. Miller DAX

RMU manual

The text of the DAX hardware manual was relatively complete and easy to follow. However, the manual had a major flaw: all of the figures, including wiring diagrams, were missing. This problem appeared to be a printing or publishing error; the company obviously meant to include figures in the manual because captions were printed adjacent to blank spaces that were evidently reserved for the graphical content.

Cellular modem manual

The cellular modems were pre-installed at the factory, so instructions were not required.

Instructions for solar power system and accessories

Adequate instructions were provided for the solar power system.

Results: Metretek CPM-II

RMU manuals

Five hardware manuals were provided for the CPM-II: one each for the modular S-Modem, the CPM-II unit, the power interrupter,the cellular modem, and the solar power unit. A separate software manual was also provided. The manuals were mostly complete and very descriptive, but there were no wiring schematics. Switching back and forth between the manuals was somewhat confusing and cumbersome. Technical support from the manufacturer was required during installation in spite of the detailed instructions.

Cellular modem manual

The cellular modems were pre-installed at the factory, so instructions were not required.

Instructions for solar power system and accessories

Adequate instructions were provided for the solar power system.

Step 2: Evaluation of Hardware Installation Procedures

As described in Chapter 4, two RMUs from each manufacturer were installed at Canaveral Lock, FL. The RMUs were evaluated for ease of installation. Installation and initial testing problems were documented. The manufacturer support required during this process was noted and appraised as to speed, clarity, and effectiveness of response.

Results: Borin Comanche

RMU installation

The Borin Comanche equipment was difficult to install. Once the first unit had been installed correctly, however, the second unit was much easier to install. A high level of technical support was readily available from the manufacturer for any questions or problems occurring during the installation.

Several factors accounted for difficulty of installation. One factor was insufficient documentation was provided for the CP application. As noted previously, the Comanche units can be used for many applications and are therefore designed with slots that can hold a variety of circuit boards (i.e., cards) in different configurations. Letter codes were used in the manual to identify the cards, but they did not match the letter codes on the configuration form that was shipped with the RMUs. The manual did not provide enough information to allow the user to determine the function of the cards according to their locations in the slots. Therefore, the proper designations had to be determined by inspection and matched with the corresponding board reference in the manual. There were no wiring diagrams provided for the RMUs; only channel voltage or current ranges and terminal locations were provided. This was very confusing and required an electrical engineer and a corrosion engineer to sort out the details.

As noted previously, a power supply for the AC-powered unit was not included in the original shipment, and this was not discovered until the site visit when it was time to install it the equipment. Borin Manufacturing was notified, and they immediately shipped a new power supply by overnight mail.

Also as noted previously, Borin did not provide the relay switches that are required for measuring IOP, nor did they supply any wiring diagrams or instructions indicating how to connect a relay. The necessary relays were purchased from a local electronics store.

The rectifiers at Canaveral Lock had a common negative terminal and individual positive terminals for each of the eight circuits. Thus, the best way to interrupt the current was to place the relay on the rectifier's negative output. (Interrupting it on the positive side would have required a relay in each of the eight circuits.) The RMUs had to be configured to allow this installation of the relay in this way, but the Borin unit easily accommodated the configuration.

Weatherproof enclosures with locking hasps were specified in the contract. Most of the enclosures provided either were not weatherproof, did not lock, or both. The solar power storage battery enclosure was the only Borin Comanche enclosure with a locking hasp. The RMUs were self-enclosed and did not have a locking mechanism. The enclosures were sealed but did not appear to be very durable. A better solution would have been to use a weatherproof enclosure containing all of the Comanche equipment.

The connectors for external wiring on the Comanche were difficult to use, especially those used for the incoming power supply. There was less than 0.5 in. of clearance for the installer to insert the power supply leads into the connections and it was almost impossible to maneuver tools, hands, and wires into the correct position.

Cellular modems/transceiver installation

The transceivers required a DC power supply and the enclosures provided did not appear to be durable. An additional weatherproof enclosure for the transceivers was purchased.

The Motorola transceivers for both units were AC-powered with an AC- to -DC converter. This configuration violated the specifications for the solar-powered Comanche, for which all of the equipment was to have been solar-powered.

There were no problems with the Borin cellular service provider.

Solar panel and power supply installation

The solar panel and attached power supply were wired according to the diagrams provided with the equipment. One problem was that the electrical contractor had turned off the power breaker for the solar power supply. Once this was discovered and the breaker was turned on; the unit then functioned properly and the solar panel worked well.

The solar power supply contained a very large storage battery and was more than adequate for this application.

Technical support

Borin Manufacturing provided excellent customer support with several engineers visiting onsite, ensuring that the difficulties encountered did not significantly delay the project.

Results: M.C. Miller DAX

RMU installation

As noted previously, the hardware manual for installation of the Miller DAX was adequate, but the instructions were unclear due to the lack of wiring diagrams and figures. Some of the installation problems were overcome because the DAX unit included clearly labeled channel and polarity terminals. The lack of wiring diagrams was confusing to the electricians, however, and they reversed the polarity of the power supply during installation, resulting in a blown fuse.

Miller did not provide the relay switches that are required for measuring IOP. The manual contained basic written instructions for installing an external relay, but there were no figures or wiring diagrams to help the electrician make the proper connections. The terminal markings for the internal DAX switch channel were adequate to make up for this shortcoming, and the necessary relays were purchased from a local electronics store.

As noted above, the configuration of the rectifiers required that the current output measurements be made in the negative circuit. The RMUs had to be configured to allow this, but the DAX unit easily accommodated this configuration.

The entire DAX equipment case was found to be easily disassembled in the field. This helped make installation easier. The plug-in wiring connection blocks provided at both ends of the DAX were mounted using knurled thumb-screws. The blocks could be easily removed and reattached, which greatly eased the connection of wires to the side-mounted terminals. The same types of thumb-screws were used to hold the DAX module to the cabinet mounting panel. Similarly, the complete RMU system, including the DAX, current interrupter components, back-up battery, power supply, and battery charging system are all mounted on a single panel held in place within the cabinet by four wing nuts. The entire system may easily be removed from the enclosure and replaced by removing the four wing nuts and disconnecting the power and monitoring point lead wires.

All of the equipment for the DAX, except for the solar panel and external modem antenna, were within the weatherproof enclosure provided with the units. The M.C. Miller DAX enclosures were the only ones that came with locking hasps as specified in the hardware requirements.

Cellular modem installation

The cellular modem was integrated into the weatherproof enclosure and was correctly wired before being shipped from M.C. Miller.

There were no problems with the cellular service provider for the DAX units.

Solar panel and power supply installation

The solar system power storage battery was mounted in the equipment case. Instructions were provided for the solar panel installation, but they were overlooked by the electrical contractors. As a result, the battery in the solar unit was ruined because the electricians reversed the leads from the solar panel. A solution would have been to include the solar panel wiring diagrams in the DAX installation manual. The battery was replaced with a new one.

Technical support

The M.C. Miller Company provided excellent customer support with several engineers visiting onsite, ensuring that the difficulties encountered did not significantly delay the project.

Results: Metretek CPM-II

RMU installation

The Metretek CPM-II was somewhat complicated to install and service. The manuals must be studied thoroughly, and most first-time users will probably find the installation procedure to be confusing because of the numerous steps involved. However, once the user has completed a CPM-II installation, future installations should be simpler. Approximately 15 jumpers must be correctly positioned in the RMU to configure it. The local level of technical expertise and level of technical support available from the manufacturer will be critical in assuring that these jumpers are set correctly.

The jumpers were initially set incorrectly because of a nonuniform labeling scheme used on the printed circuit board associated with these jumpers. It is unknown whether this occurred at the factory or during installation.

Special attention should be given in advance to which terminals in the RMU should be used because there are several options for configuring the rectifier. Different terminals are used depending on the voltage ranges that are expected.

An important portion of the installation required configuring the system as a "high side shunt" or a "low side shunt" system based on a short testing procedure. "High side shunt" indicates that the shunt to be used for making rectifier current measurements is wired in series with the anode (positive) rectifier terminal. "Low side shunt" indicates that the shunt is wired in series with the structure (negative) terminal. The electricians had problems following the test procedure and configured the unit improperly. The result was that two important channels were burned out and the main unit board had to be replaced. Someone with CP experience was needed to conduct and interpret the short test.

Due to problems with the cellular phone service (described in a later section), the units could only dial out. This means that any changes to the configuration had to be performed onsite.

Metretek was the only manufacturer that provided relays with their units. However, the proprietary relay was incapable of working properly at the test site. Metretek technical support reported that the relay configuration at the Canaveral site would not support their proprietary relay and therefore IOP readings could not be obtained.

As discussed above, the configuration of the rectifiers required that the current output measurements be made in the negative circuit, and the RMUs had to be configured to allow this. This was a problem for the Metretek units, and the method for solving it was not covered in the hardware manuals. Metretek technical support personnel provided guidance by phone to overcome the problem.

All of the components that required protection from the environment were enclosed in weatherproof enclosures. The relay switches had separate enclosures. The relay switch enclosures had locking hasps, but the RMU enclosures did not.

Cellular modem installation

The cellular modem was integrated into the weatherproof enclosure and was correctly wired before being shipped from Metretek. The modem in the solar unit was configured so that it was unable to accept incoming calls. This was done to minimize the amount of power required. Metretek engineers stated that configuration changes to the CPM-II could be made when it contacted the master computer. The AC-powered system was configured to accept incoming calls.

There were major problems with cellular service provided to the Metretek units, as discussed at the end of this section. The result was that communication was not possible between the master computer and the RMUs through most of the evaluation. Metretek technical support did not provided a satisfactory resolution for this issue.

Solar panel and power supply installation

The solar system power storage battery was mounted in the equipment case. Instructions were provided for the solar panel installation. There were no problems with installation of the solar power system or the AC power supply. The power supply was an AC- to -DC converter.

Technical support

The level of technical support provided by Metretek was significantly lower than that provided by the other two manufacturers. Metretek personnel were present onsite during two of the three site visits to provide assistance. However, their average response time for technical support requests throughout the evaluation period was significantly longer than those of the other manufacturers. Key support personnel were frequently unavailable for several days at a time.

Analog Cellular Service Issues

Manufacturers of all of the evaluated units were required to provide their own cellular service. All of the RMUs used analog cellular modems. It is believed that the manufacturers have elected not to pursue the use of digital modems yet because there are three different digital protocols instead of one nationwide standard. National cellular service providers only offer digital service, so analog cellular service must be obtained from local providers. As local providers also begin switching to digital service, this issue will become more important.

Some local cellular providers made logistics more complicated by requiring the Army to provide a point of contact and billing address within the service area. One cellular provider delayed progress 3 weeks by requiring a credit check of the RMU manufacturer.

Another problem was that the local carriers required that the RMU modems be activated in the same area code where they will be used (in the current case, within Canaveral Lock's area code of 407). This makes it impossible for a manufacturer not located within the same area code as the site to completely program and configure the RMUs at the factory. In the current case this problem was solved because of a coincidence. During the time the RMUs were being constructed and programmed, all of the RMU manufacturers attended a conference in nearby Orlando. They were therefore able to visit the Canaveral site and activate the modems at a minimal cost.

There were communication problems with the Metretek CPM-II throughout the test period. The units were generally unable to accept incoming calls. When dial-in contact was attempted, the typical response was a recorded message stating that there was "no service provider."

The research team found that the problems were largely due to the terms of Metretek's contract with their cellular service provider. Technical support personnel from the cellular service provider stated that if an analog cellular device does not change locations and does not receive calls over a period of time, the device is designated as inactive and its telephone number is removed from the access database. It was determined through experimentation that this period was approximately 4 days. After this amount of time has passed, the device is able to make outgoing calls; however, it must be re-initialized by the cellular provider to enable it to receive calls again. This usually required several telephone calls to the provider. The net result was that the Metretek units could only make outgoing calls throughout most of the evaluation period.

It is interesting to note that Borin used the same cellular service provider, but there were no problems with contacting the Comanche units. The terms of Borin's contract were different.

This service problem would seem to encourage RMU manufacturers to pursue a digital modem solution for communications. One form of digital communication must be selected, especially since the problems with the service provider do not occur for digital communication modems connecting with the local analog signal.

Step 3: Evaluation of Software Manuals

The software manuals were evaluated for clarity, completeness, and conciseness. A good manual should clearly present the procedures necessary to install the software on the master computer. System requirements should be clearly identified. Procedures for using the software, setting the necessary operating parameters, obtaining data, exporting data to a spreadsheet, and enabling automated monitoring features should be explained clearly and in detail.

Results: Borin Comanche

The software manuals did not provide enough information for the installation, configuration, and use of the software without technical assistance from the manufacturer. The configuration of the software was very complex and some of the voltage ranges for configuring the data channels were not specified. A detailed knowledge of each data channel as configured onsite was required.

Some important functions, such as accessing data history or exporting data to a spreadsheet program, were not covered.

One useful feature is that the manual is available online in PDF format so the user can download the most recent version.

Results: M.C. Miller DAX

The software manual for the DAX system was considered adequate for novice and expert RMU users. The manual provided a step-by-step procedure for initializing the DAXit software and initiating contact with the DAX unit. DAX settings, such as channel voltage ranges or RMU-specific information, were not required as they could be downloaded directly from the unit.

The remainder of the manual consisted of the printed help files from the software, with some repetition. Some limited examples provided in the manual illustrated the uses of various commands. Additional examples would have been helpful. A bigger help would have been the addition of page numbers, a page-numbered index, and a table of contents.

Results: Metretek CPM-II

The software manuals for the CPM-II system were thorough and were considered adequate for a moderately experienced RMU user. A novice user would be expected to have some difficulties. Even the experienced user who typically requires very little assistance in configuring software would need to read the manual thoroughly, because of the large number of options available their functional definitions. The initial configuration of the software was not discussed adequately in the manual itself, but supplemental instructions were provided to help with some of the issues.

The configuration of the software was very complex. The configuration can be performed by carefully following the instructions in the manuals, and especially the initial configuration in the supplemental instructions. The CPM-II system has two sets of software, with separate manuals for each set. One manual is for the cathodic protection monitoring and control (CPM) software; the other is for the unit's electronically erasable and programmable read-only memory (EEPROM) software, which is used to program the EEPROM in the monitoring and control module (MCM). The EEPROM software is required for naming the CPM-II RMU and implementing the autodial feature for alarm reporting.

The software manual for the CPM-II system was considered excellent in terms of its content. It provides clear, detailed, step-by-step instructions for properly setting up the software for use with the RMU. As a result of this detail and the software's versatility and power, the manual is lengthy and requires many hours to read thoroughly. It provides good illustrations of most input screens and gives some examples to assist in selecting various software settings. However, it may leave the novice user unsure of some selections. More discussion of manufacturer's preferences and/or default settings would be helpful.

No instructions were included in the software manual for configuring the software for the relays used to interrupt the DC output of the rectifier. Instead, they were located in the power interrupter manual. This caused some confusion during the software configuration process. It would be helpful to move the relay software instructions to the software manual, or at least to cross-reference them in the software manual.

Overall, there are six manuals provided with the Metretek system. It would be helpful if the manuals could be consolidated into a single loose-leaf binder and the user could be provided with general guidance on the setup process.

Step 4: Evaluation of Software Installation, Configuration, and Technical Support

Installation and configuration procedures were evaluated according to software loading time required, ease of configuring the software to perform the desired measurements, and the amount of technical support required. Configuration or compatibility problems and issues were recorded along with the appropriate solution.

Results: Borin Comanche

Software installation

The Comanche software was provided on a compact disk (CD) from the manufacturer. The software was also available online at the Borin web site and could be copied to floppy disks. There were no instructions on the CD, which might cause confusion for a novice user. Installation time for the software was slightly over 2 minutes from the CD.

Software configuration

There were several problems associated with configuring the software. One problem was the need for an external security device called a "dongle," which must be attached to the computer's parallel port in order for the Comanche software to operate. The dongle configuration file did not work with the version of the software that was supplied. The software had been updated to account for year 2000 (Y2K) issues, and the old configuration file was no longer compatible with it. A new configuration file was requested from Borin through their online request process. It arrived within two days and fixed the problem.

Another dongle issue is one of convenience. The dongle is preconfigured by the manufacturer to allow access only to specific RMUs. This means that if additional RMUs are acquired, new dongles or new configuration files for the dongle must also be acquired. All computers that will be used for communicating with the RMUs must be equipped with their own external dongles and there are difficulties getting multiple dongles to work with the same units. This could be very inconvenient if multiple computers (for example, one onsite and one at a District office) are to be used for contacting the RMUs. Furthermore, sometimes changes to the software (such as the Y2K change described above) will require an updated dongle configuration file. This is also an inconvenience to users.

Another problem with the dongle arose on machines that are running Windows NT. The dongle required the use of a parallel (LPT) port. Parallel ports on Windows NT machines typically are disabled. Although the dongle allowed signals to pass through to the printer, the software will not operate on a machine with a disabled parallel port. The version of the software evaluated during this project was limited to machines with working parallel ports that are not configured to use the NT operating system.

Borin released a new version (version 5.2) of their software in late October 2000, after the current evaluation was completed. Version 5.2 reportedly can be evaluated for 90 days without the dongle. Furthermore, compatibility problems with Windows NT have reportedly been solved with a software patch.

Another issue was the limited support of communication (COM) ports. The version of the software evaluated during this project supported a very limited number of modems and it required the modem to be connected to COM1 or COM2. Many new computers and laptops (including one used during this evaluation) do not have the type of modem required and may have their modems connected to the COM3 or COM4 port. Such computers would require an external modem in order to use the Borin software. The version of the software evaluated during this project is best suited for use with slightly older computers that have the Windows 95 operating system.

It should be noted that the new software version 5.2 reportedly supports modems attached to COM3 and COM4, and also supports more types of modems, so this may no longer be an issue.

Additional technical support was required for configuring the channel ranges for the remote monitoring units. All of the channel ranges had to be preset in the software prior to contacting the Comanche unit. The software was not very intuitive and required a complete knowledge of the RMU's configuration. Detailed information on these topics was not contained within the manual, and some of the help files were missing for several of the windows used in the Comanche software.

Security has become an important issue in the RMU market. An initial password was required to enter the Comanche software. The password was provided within the manual. It was relatively easy to set up software permissions for multiple users.

Technical support

Online technical support was available for basic questions involving the configuration issues. The technical support was excellent, both online and by phone. Response times were within a day for the former and immediate for the latter. Follow-up support was also excellent.

Results: M.C. Miller DAX

Software installation

The M.C. Miller DAXit software was supplied on four 3.5 in. floppy disks. Installation time was approximately 2 to 3 minutes.

Software configuration

The DAXit software required the user to obtain an initial password from the manufacturer that was good for a day after the telephone conversation. Once the security access was set, configuring the software was a simple matter. All that is required to establish contact with the RMUs is the telephone number and an installed modem on any port. The user does not need any information about the RMU configuration; the software downloads it automatically from the RMU.

Some difficulties arose for a computer with multiple modems. That problem was bypassed by ensuring that only one modem was installed within the software package.

The software allows the user to completely reconfigure RMUs from the master computer. This includes definitions and labels for all of the ranges and offsets for each channel. Other downloadable/uploadable configurations include the types of measurements taken on each channel, alarm levels (both upper and lower limits), unit ID number, etc. In addition, the unit's EEPROM can be completely reconfigured when the operating software for the RMU is updated or upgraded. This means that the user does not need to travel to the RMU to perform any of these operations.

More flexibility occurs because multiple RMUs with the same configuration can be batch-configured by copying the configuration from one RMU to another. The software is very intuitive, and most users should be able to download configuration information and take readings within several minutes of installing the software. Additionally, when DAXit software is upgraded, the RMU software can be upgraded remotely from the host computer.

Technical support

Technical support was considered excellent for the DAXit software, and questions were usually handled immediately.

Results: Metretek CPM-II

Software installation

The CPM-II software is contained on seven diskettes. It took approximately 20 minutes to fully load, which was considerably longer than the loading time for other units. The package included the database software, as well as Borland ReportSmith, which produced reports and graphs from the remote unit data. ReportSmith also provided a data export capability. The EEPROM software is contained on one diskette and takes only about 1 minute to load. It is absolutely necessary to review the manuals before attempting to use the software because some of the screens are not self-explanatory.

Software configuration

The majority of the CPM software was relatively easy for an experienced user to configure when the manual was followed closely. However, novice users would be expected to have some difficulties. A full configuration for a CPM-II unit should take less than 15 minutes after the user has become familiar with the software and hardware.

The version of EEPROM software used in this evaluation required a direct connection between the COM1 port of the programming computer and the CPM-II unit using a special cable that was supplied with the RMU. Consequently, this step in the configuration procedure required someone to go to the RMU in the field with a portable computer and program information into it. (A new version of the EEPROM software that permits remote programming is reportedly available, but it was not evaluated in this demonstration as the units were only capable of calling out.)

The configuration required modification of the Borland application programming interface database, which was not required for the other RMU software.

Technical support

There was no phone number given in the manual for technical assistance, but the vendor's order line provided a name and toll-free number for technical questions. It was sometimes difficult to get immediate assistance, but calls were generally returned within a day or two.

Step 5: Evaluation of Software Use

Software was evaluated throughout the RMU demonstration period addressing the following issues:

- Ease of operation (user-friendliness).
- Software versatility. A good software package should be easily adaptable to a variety of situations and configurations. Versatility addresses such issues as whether the software can interrogate both single units and multiple units, or whether the software allows remote configuration of the RMU.
- Software interface appearance.
- Help function. This refers to the usefulness and completeness of the online help feature.
- Data report format. This refers to the clarity, flexibility, and appearance of the standard data reports produced by the RMU software.
- Exportability. This refers to the ability of the software to organize and format data for use by other programs such as spreadsheets.

- Alarm capability. This refers to an automatic alarm to notify the operator if a problem has occurred with the CP system.
- Synchronized interruption. This refers to the ability of the software to interrupt several rectifiers simultaneously.
- Availability of a software uninstall feature.

Results: Borin Comanche

Ease of operation

The Borin software was found to be powerful and flexible, but difficult to operate. It seems to be designed primarily for periodic scheduled reporting, as opposed to allowing the user to dial in directly to request readings.

When the user starts the program, it is not obvious how to contact the units and take measurements. Familiarity with the software is required in that the user has to navigate through several button bars and menus. This interface design is different from the other two packages, which very clearly provide a method for the user to contact the units and take data directly from the software's opening screen.

Sometimes several calls to the RMUs were required to obtain data. Sometimes the units did not answer the call, which may have been caused by noise in the cellular connection. Sometimes the units would answer and then hang up before providing data. Once a connection was established, the units often had to be queried two or three times before data were received at the master computer.

It is difficult to measure both an on potential and an IOP during one phone call. The user must manually set the date and time in the software for each reading he or she wishes to obtain. Only one reading can be set up at a time, and there is a delay required between readings. Thus, if the user wants to measure both potentials, he or she first sets the date and time for the on potential reading and places the phone call. The on-potential reading is conducted at the set time. Then, the user must manually change the date and time settings in the software to conduct the instant-off potential reading, making sure that the required delay time will have elapsed. The result is that the phone call will be several minutes long, or two phone calls will be needed.

The software was able to provide history reports and plots and was able to export the data to Microsoft Excel. However, the methods for doing this were not documented in the software manual or on any of the Borin web pages, and instructions could only be obtained by calls to Borin technical support personnel. The procedure was difficult and consisted of many steps to be performed in a specific sequence. It did not work if any step was performed out of sequence. The procedure also required use of the Borin Command Center, a software module which was very poorly documented and would only operate if the RMU software was executed first.

Software versatility

The Comanche software versatility was considered excellent. It allows for monitoring of single or multiple units, real-time alarm reporting, and rectifier on/off synchronization. Multiple units can also be treated as a group. Two-way communication for control and monitoring purposes is supported, and alarm reporting is supported.

Help function

The help function provided with the software was considered inadequate for most of the windows, but the help files lacked some pertinent data or did not exist for some of the Comanche windows.

Data format

Well-formatted data history reports and plots can be generated. However, as noted above, the procedure for doing this is not documented and is buried in the software. Evaluators were unable to obtain these reports from the software without technical support from the manufacturer.

Exportability

The Comanche software is capable of exporting data to spreadsheet software such as Microsoft Excel, but the procedure for doing this is not documented and is buried in the software. Evaluators were unable to export data from the software without technical support from the manufacturer.

Alarm capability

The Comanche RMU was provided with automatic alarms that would notify the operator if a problem had occurred with the CP system. The alarm capability was not tested in this evaluation.

Synchronized interruption

The software implemented a synchronized interruption capability using any one of the rectifier RMUs as the master synchronizing unit. However, there was very little mention of how to execute the interruption in the user manual or help files. The master unit is supposed to regularly contact each of the other units to be interrupted, and simultaneously keep units synchronized to interrupt within 30 milliseconds of each other. The synchronized interruption capability was not evaluated.

Uninstall feature

The Borin Comanche software does not have an uninstall feature. Complete removal of the software, unless it is installed in conjunction with a quality uninstall program, may be difficult or even impossible. If conflicts appear between the host computer and the CPM software, the lack of an uninstall feature could make the problem difficult to eliminate without reformatting the entire hard drive and reinstalling all software.

Results: M.C. Miller DAX

Ease of operation

The software configuration of the DAX RMU is both simple and intuitive. Routine operation is equally simple and intuitive. With the push of a button, the DAX automatically places a phone call to the RMU, makes all of the requested measurements (including IOP), stores them in the data history, and hangs up. Typically, the user can perform data readings in 30 to 60 seconds per unit. The program easily exports data to a variety of common programs, including Microsoft Excel. Up to 1000 readings can be stored in the reading history. Configuration changes or software upgrades can be transferred between the host computer in either direction with the push of a button.

The software is compatible with Windows 3.1, 95, 98, and Windows NT.

Software versatility

The DAXit software versatility was considered excellent. The software allows for easy monitoring of single or multiple units, real-time alarm reporting, and rectifier on/off synchronization. Multiple units can also be treated as a group. Two-way communication for control and monitoring purposes is supported, and alarm reporting is supported.

Help function

The help function provided with the software was considered excellent. The style was similar to the on-screen help typical of most Windows applications. The level of detail was similar to the manual. The function was easy to use and allowed the user to click on the highlighted words in the help file for more information on a related topic. The help function would be very useful for both experienced and novice RMU users.

Data format

The data are presented in a very clear format resembling a spreadsheet. The entire data history can be viewed or plotted easily. Reports can be easily generated in tabular form.

Exportability

The DAXit software allows data to be easily exported to any standard spreadsheet program.

Alarm capability

The DAX RMU was provided with automatic alarms that would notify the operator if a problem had occurred with the CP system. The alarm capability was not tested in this evaluation.

Synchronized interruption

The DAXit software supports a synchronized interruption capability using any one of the rectifier RMUs as the master synchronizing unit. The master unit regularly contacts each of the other units to be interrupted via modem, and simultaneously keeps up to 50 units synchronized to interrupt within 30 milliseconds of each other. The synchronized interruption capability was not evaluated.

Uninstall feature

The built-in uninstall feature within the software package was powerful and useful. It quickly and automatically removes the DAXit program, its subdirectories, and all associated system files and settings, but it does not delete the record history. The software could easily be upgraded and reinstalled with no problems.

Results: Metretek CPM-II

The evaluation of the Metretek unit was based on a truncated (i.e., 3-week) time period when communication with the unit was possible.

Ease of operation

As discussed previously, the CPM-II software is somewhat difficult to set up. Once setup is complete, it has an attractive, well organized Windows-based interface. The software is relatively user friendly once the user is accustomed to working with multiple modules. Each module is attractively presented and well organized, providing the same feel as most other well designed Windows applications.

Software versatility

The CPM-II software versatility was considered good. When configuration is complete, the software is easy to use and comes with report and graph generating software. The software supports monitoring of single or multiple units, real-time alarm reporting, and rectifier on/off synchronization. Multiple units can also be treated as a group. Two-way communication for control and monitoring purposes is reportedly supported, but could not be tested because of the previously noted problems with cellular phone communication.

Help function

The help function provided with the software was considered excellent. The style was similar to the on-screen help typical of most Windows applications. The level of detail was similar to the manual. The function was easy to use and allowed the user to click on highlighted words in the help file for more information on a topic. A help icon is also available in the Metretek program group. This can be more convenient than using the printed manual.

Data format

The standard data reports provided by the CPM-II software were clear and easy to read. The Metretek system uses a report-generating software package called Borland ReportSmith, which utilizes the Paradox database engine. ReportSmith produces attractive reports and graphs of data gathered by the unit. Reports can be generated for combinations of units and combinations of monitored/controlled parameters, and data can be viewed in either tabular or graphical format. A variety of user-selectable report formats is provided, including bar graphs, line graphs, area graphs, and pie charts. Full editing capability is provided for graphical formats.

Exportability

The data can be exported into a spreadsheet program such as Microsoft Excel or Lotus 1-2-3 through the use of Borland's ReportSmith, which is included.

Alarm capability

The CPM software supports the setting of alarm conditions to notify the operator that a problem has occurred in the CP system. The user can set the number of "out-of-limit" events allowed to occur before the alarm is triggered. This feature guards against false alarms.

Alarms can also be set to report AC power interruptions, activation of the anti-tampering switch, communications errors, clock synchronization problems, and several others. Alarm logging and reporting are flexible; alarm events can be reported immediately, during a scheduled call in from the RMU, or during a poll from the host computer. The alarm capability was not tested in this evaluation.

Synchronized interruption

The CPM software supports synchronization of the clocks of multiple units. This in turn permits synchronized interruption of multiple rectifiers through CPM software control. According to Metretek, their proprietary modem is necessary for the CPM-II to provide synchronized interruption. Based on this requirement, the desktop computer must regularly communicate with each RMU being simultaneously interrupted. This approach could result in long-distance telephone charges if the master computer is not within the same local access area. The synchronized interruption capability was not evaluated during this project.

Uninstall feature

The CPM-II software does not have an uninstall feature. Complete removal of the software, unless it is installed in conjunction with a quality uninstall program, may be difficult or even impossible. If conflicts appear between the host computer and the CPM software, the lack of an uninstall feature could make the problem difficult to eliminate without reformatting the entire hard drive and reinstalling all software.

Step 6: Evaluation of Hardware Features

RMU hardware abilities and reliability were rated. A log of all problems encountered throughout the evaluation was maintained. The manufacturer support required during this process was noted and appraised as to speed, clarity, and effectiveness of response. Other factors and features considered included safety, surge protection, reliability of the relay that interrupts the CP current, and ability to program the RMU remotely from the master computer.

Results: Borin Comanche

The Borin Comanche units performed very well throughout the evaluation. Problems that did occur arose from cellular modem difficulties.

Backup battery

The Comanche units were originally supplied without backup power supplies for either the transceiver or for the AC-powered RMU. This condition was considered to be unsatisfactory because the units would not operate during a power failure.

The lack of a backup power supply was especially a problem at Canaveral Lock. Power outages occur frequently at Machine House 3 (where the Comanche units were installed). The AC junction box that provides all of the power for the lock CP systems is located in Machine House 1, and AC power to Machine House 3 is interrupted each time the lock gates are opened or closed. Thus, the AC-powered Comanche RMU and the transceivers for both Comanche units were not operational during the opening/closing of the gates. However, both the units and transceivers were functional once the gate operation completed. Borin Manufacturing reported that they had solved the problem by adding rechargeable backup power supplies to both units.

There was another related problem that manifested itself during power outages. The original configuration of the Comanche required a delay of approximately 90 seconds between the powering-on of the RMU and the powering-on of the transceiver. If the RMU and transceiver were powered on at the same time (as would be expected after a power outage), the cellular modem would not work.

Safety and warning labels

The RMUs used a 12 volt DC power supply. An AC to DC converter was used for the AC-powered unit. For the solar unit, the solar panel was connected to the battery and set to provide 12 volt DC power. Safety warning labels were not present in any of the Comanche equipment.

Channel type

The Comanche units were equipped with full differential channels. This is a beneficial feature, especially if a single unit will be used to monitor multiple structures that are electrically isolated from each other.

Surge/lightning protection

Surge protection was provided for all of the power inputs and leads into the RMU.

Remote programming

The Comanche RMUs could be reprogrammed remotely. This feature was extensively used because the Comanche would not take reference cell IOP during the same connection without user intervention.

Relays and IOP readings

As mentioned previously, Borin did not supply the relays required for IOP readings. Relays were purchased from a local electronics store and installed according to guidance from Borin. The Comanche RMUs were able to correctly operate the relay and obtain IOP measurements.

Cellular communication

On one occasion, digital communication to the units was interrupted (although it was available onsite for the lock personnel). The other units on the same machine house had the same problems, so this was considered to be a cellular service problem and not a problem with the units themselves. On two separate occasions, multiple connections were required to obtain data due to noise in the modem connection.

Solar power

The solar power supply provided adequate power throughout the evaluation.

Reliability

The Comanche units were installed in a very harsh marine environment during the rainy season. The evaluation occurred throughout the seasonal change. The RMUs performed well, with only minimal interruption due to the cellular communication issues described above. The units were therefore judged to be very reliable over the short period of this evaluation. Evaluation of longer-term reliability would require a longer test period.

Results: M.C. Miller DAX

One hardware problem arose with the solar-powered modem during the evaluation, as described in the section below on cellular communication. The units otherwise performed reliably throughout the evaluation.

Backup battery

An adequate backup battery was provided for both the AC- and solar-powered DAX units.

Safety and warning labels

Power was supplied to the units directly from an AC power outlet or from the solar panels. The DAX was the only unit in which power was taken directly inside the equipment case via the 120 V AC electrical service. The other units took power from a wall outlet via a detachable power cord with an AC adapter, which is a safer and more practical way to power this kind of equipment. Safety warning labels about the 120 V AC input were prominently displayed within the DAX equipment boxes.

Channel type

The DAX units were equipped with full differential channels. This is a beneficial feature, especially if a single unit will be used to monitor multiple structures that are electrically isolated from each other.

Surge/lightning protection

Surge protection was provided for all power inputs and leads into the DAX RMU.

Remote programming

The DAX RMUs could easily be remotely reprogrammed. This feature was used to establish the communication interface at Canaveral Locks. All configuration information was stored on both the DAX and within the DAXit software package.

Relays and IOP readings

As noted previously, M.C. Miller did not supply the relays required for IOP readings. Relays were purchased from a local electronics store and installed according to guidance from Miller. The DAX RMUs were able to correctly operate the relay and obtain IOP measurements.

Cellular communication

The modem in the AC-powered unit malfunctioned shortly after installation and there were initial problems with the accuracy of the data. M.C. Miller company performed remote diagnostics from their factory and found that the unit had been disassembled and reassembled improperly during installation. This error may have in part been due to the lack of figures in the installation manual. Miller fixed the problem onsite and no further problems occurred with the AC-powered unit.

A problem also occurred with the cellular modem on the solar-powered DAX. Apparently, a surge occurred in the system, possibly due to a lightning strike. M.C. Miller was contacted once the problem was discovered. A technician was sent to the site the following day and the unit was taken to the factory for diagnostics. The unit was returned to the site the following day, after the diagnostics, and reinstalled. It was impossible to determine if the problem affected the other units at Machine House 1 because of the ongoing communication problems with the Metretek CPM-IIs.

Solar power

The solar power supply provided adequate power throughout the evaluation period.

Reliability

The Miller DAX units were installed in a very harsh marine environment during the rainy season. The evaluation occurred throughout the seasonal change. Despite the issues previously noted, once configured, the units performed well with only minimal interruption. The units were therefore judged to be reliable over the short period of this evaluation. Evaluation of longer-term reliability would require a longer test period.

Other hardware concerns

Near the end of the evaluation period, M.C. Miller reported that the microprocessor that operates the DAX system hardware is no longer available from the manufacturer (Motorola). Therefore, this specific DAX hardware is no longer available. M.C. Miller reports that new hardware using a different microprocessor is under development and may be available by fall of 2001. The manufacturer has stated that they are committed to the development of replacement hardware using a different microprocessor and that the new system will use the same software. This new hardware will reportedly be limited to solar power and cellular communications.

Results: Metretek CPM-II

The evaluation of the Metretek unit was based on the truncated (3-week) time period when communication with the unit was possible. Because of the cellular communication problems, it was generally difficult to evaluate the performance of the CPM-II.

Backup battery

An adequate backup battery was provided for both the AC- and solar-powered CPM-II units.

Safety and warning labels

The RMUs used a 12 volt DC power supply. An AC- to -DC converter was used for the AC-powered unit. For the solar unit, the solar panel was connected to the battery and set to provide 12 volt DC power. Safety warning labels were affixed to all of the Metretek equipment.

Channel type

The Metretek units were equipped with full differential channels. This is a beneficial feature, especially if a single unit will be used to monitor multiple structures that are electrically isolated from each other.

Surge/lightning protection

Surge protection was provided for all of the power inputs and leads into the CPM-II RMU.

Remote programming

The CPM-II RMUs could be reprogrammed remotely, but this feature could not be evaluated during this project because direct dial-in communication with the units could not be established. Both units were only able to dial out during the 3 weeks when remote communication was working at all. The RMUs are not designed to be reprogrammed in that mode.

Relays and IOP readings

The CPM-II requires a proprietary relay to make IOP readings. These relays were installed on both RMUs. The proprietary relay did not work during this evaluation and IOP readings could not be obtained. Metretek technical support personnel reported that their relay would not work in the configuration at the Canaveral test site where 3 RMUs were set up to monitor the same rectifier and structure. It should be noted that the relay did work during an earlier study at Fort Drum (Van Blaricum et al. 1998).

Cellular communication

The problem with the cellular service provider for the Metretek units has been discussed in previous sections of this report. Reliable cellular communication was never established with the Metretek RMUs.

Before the RMUs were installed, the cellular provider claimed that the service plan would provide adequate coverage for the evaluation. This was clearly not the case since the provider automatically deactivated the phones if they were not used for several days (such as over a long holiday weekend). However, to the best of CERL's knowledge, Metretek did not attempt to remedy the situation by changing providers or by changing the terms of their contract.

It should be noted that the CPM-II functioned satisfactorily in a previous study at Fort Drum where standard telephone lines were used (Van Blaricum et al. 1998).

Solar power

The solar power supply did not provide enough power for the unit to function as required. It was sized to only provide enough power for the RMUs to place outgoing calls to the master computer at certain scheduled times. It was sized this way in order to cut solar panel costs. Because the cellular phone was only powered during the prescheduled times, it was unable to receive incoming calls. The RMUs were supposed to be able to download updated configuration and call scheduling information from the master computer during the scheduled calls, but this capability did not work. The RMUs were unable to download anything from the master computer. Because the RMU could not receive incoming calls, the only way to transmit information to it was to make a site visit.

The evaluation team was able to obtain data remotely from the solar-powered CPM-II for a short period of time. A problem occurred over Labor Day weekend because the master computer was offline during that time. The RMU shut itself off after it tried unsuccessfully to complete its scheduled calls. Because of the cellular communication problem, the RMU could not be reset remotely.

Reliability

At the time of this evaluation, the CPM-II RMUs were not reliable for use on structures that require cellular communication and/or solar power. They also were unable to obtain IOP readings in the configuration at Canaveral Lock. The system may perform better in a situation where the phone lines are hardwired and direct communication between the master computer and the RMUs is possible. It may also perform better in a simpler CP system configuration. As noted above, an earlier version of this system did operate properly during an evaluation at Fort Drum (Van Blaricum et al. 1998).

Other hardware concerns

The CPM-II requires a dedicated computer that is ready to communicate with the remote equipment *at all times*. This requirement did not become apparent until the Labor Day weekend incident described above. The problem was aggravated when the cellular service provider deactivated the phones after several days of no usage. The CPM-II will shut down if it is unable to make contact with the master computer within a certain period of time, and a site visit must be made to reconfigure it. This is a substantial disadvantage with this RMU. For example, a long power failure at the location of the master computer, or a failure of the master computer itself, could cause the RMU to shut down and require a site visit to reset it.

The required proprietary external modem is also a significant disadvantage. The modem is available exclusively from Metretek at a cost of approximately $1200. It is large and inconvenient to carry, and is only capable of a 2400 baud connection rate. Each computer that will be obtaining data from the CPM-II must be equipped with the special modem, which will add significantly to the cost without providing any benefit.

Step 7: Evaluation of Permanent Reference Cells

Three commercially available silver / silver chloride reference electrodes were installed with the CP remote monitoring systems for evaluation at Canaveral Locks in Florida. The selected vendors were:

1. Borin Manufacturing, Inc.
2. Electrochemical Devices, Inc. (EDI)
3. Matcor, Inc.

All reference electrodes that were installed on this project provided accurate structure-to-earth potential data during the relatively short evaluation period. The long-term stability of the reference electrodes cannot be determined without testing over an extended period.

Two of the silver / silver chloride reference electrodes installed at Canaveral Lock are of the saturated type, and thus have a reversible potential. These are the EDI and Borin electrodes. They are suitable for use in both saltwater and brackish waters, and water that varies vary between these two salinities, as is the case at Canaveral Lock.

The third electrode (from Matcor) is not contained within a saturated solution of potassium chloride like the other two. This will cause the Matcor electrode potential to vary depending on the actual chloride concentration in the water in which the cell is immersed. The measured potential change would be expected to be 59 millivolts for every tenfold increase in chloride ion concentration. This could be a problem if significant variations in chloride concentrations were expected to occur as the lock gates open and close. This is not expected to be a major problem at Canaveral Lock since the measured resistivity on the bay side of the locks was about 30 ohm-cm versus 25 ohm-cm on the ocean side.

Because of its different composition, the Matcor electrode would also be expected to have a different potential than the other two electrodes. The difference was measured by immersing the three electrodes in water from the ocean side of the locks and measuring their potentials versus a copper / copper sulfate reference electrode. The results are shown in Table 12.

Table 12. Comparison of permanent reference cell potentials, 28 June 2000.

Electrode Manufacturer	Potential vs Copper/ Copper Sulfate Reference Cell (Millivolts)
Matcor	-59
Electrochemical Devices	-106
Borin	-111

Step 8: Evaluation of Equipment Accuracy

The accuracy of the remote monitoring equipment at the Canaveral Lock test site was checked during the late September 2000 site visit by comparing the RMU readings taken remotely at the offices of Russell Corrosion with readings taken onsite with a Fluke Graphical Multimeter.

Additional remote readings were taken at CERL twice a week between mid-August and early November 2000.

Results: Borin Comanche

The field data comparing the onsite and remote readings obtained during the September site visit are shown in Table 13 and Table 14. The data indicate that the equipment is accurate for structure-to-earth potentials and rectifier voltage reading. The data also indicate that the CP system at Machine House 3 was not working properly at the time of the site visit. The rectifier was producing voltage but almost no current, and there was no difference between the structure's on potential and its IOP. This indicates a possible open circuit in the system.

It is noted that the Borin current output data were not completely accurate for extremely low (less than 1 millivolt) readings of rectifier current output shunts. This current-measurement inaccuracy would not be unexpected from an RMU when a CP system malfunctions and current drops to near-zero. Since the CP system malfunctioned throughout the entire test, however, it is unknown how accurate the Borin units would be under normal CP system operating conditions.

While the site testing in this instance indicated that the IOP data were accurate, there is a possible concern that the current interruption measurement system may be too rapid with the Comanche system. Inductive or capacitive data spikes may be included in the reading if the structure is well coated (capacitive) or is extremely long (inductive). This phenomenon should be evaluated further for well coated or extremely long structures before the Comanche system is selected for use on such structures.

Table 13. Comparison of remote and onsite measurements for solar-powered Borin Comanche RMU at Canaveral Lock Machine House 3 (20 September 2000).

Measurement	Remote Data	Onsite Data
Rectifier Voltage	16.6 volts	16.7 volts
Voltage Across Rectifier Shunt and Calculated Current*	0.6 millivolts (60 mA)	1.3 millivolts (130 mA)
Matcor Reference: On Potential	0.60 volt	0.60 volt
Matcor Reference: Instant Off Potential	0.60 volt	0.60 volt
Borin Reference: On Potential	0.67 volt	0.66 volt
Borin Reference: Instant Off Potential	0.66 volt	0.66 volt

*The current in parentheses was calculated using the shunt rating of 50 millivolts = 5 amps.

Table 14. Comparison of remote and onsite measurements for AC-powered Borin Comanche RMU at Canaveral Lock Machine House 3 (20 September 2000).

Measurement	Remote Data	Onsite Data
Rectifier Voltage	16.87 volts	16.79 volts
Voltage Across Rectifier Shunt and Calculated Current*	0.7 millivolts (70 mA)	0.0 millivolts (0 mA)
Matcor Reference: On Potential	0.66 volt	0.66 volt
Matcor Reference: Instant Off Potential	0.66 volt	0.66 volt
EDI Reference: On Potential	0.61 volt	0.61 volt
EDI Reference: Instant Off Potential	0.61 volt	0.61 volt

*The current in parentheses was calculated using the shunt rating of 50 millivolts = 5 amps.

The data measured remotely at CERL were plotted for each machine house. Results for the Borin Comanche units are included in the plots for Machine House 3 in Figure 28 through Figure 31. The plots show that all of the RMUs on Machine House 3, including the Borin Comanches, gave similar results for all of the parameters measured. The measurements are also in line with the results from the September site survey.

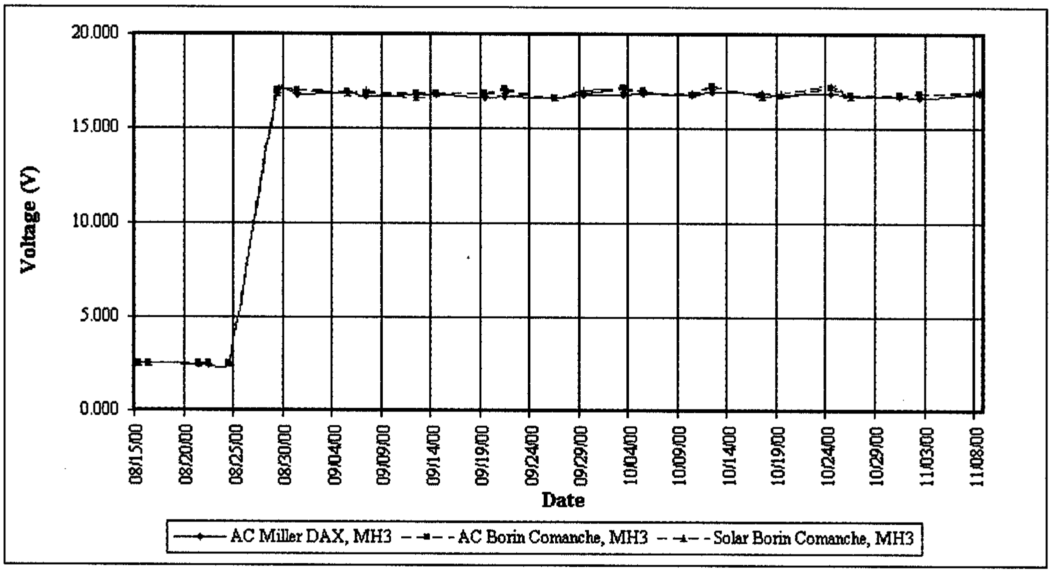

Figure 28. Rectifier output voltage at Machine House 3 (measurements taken remotely at CERL).

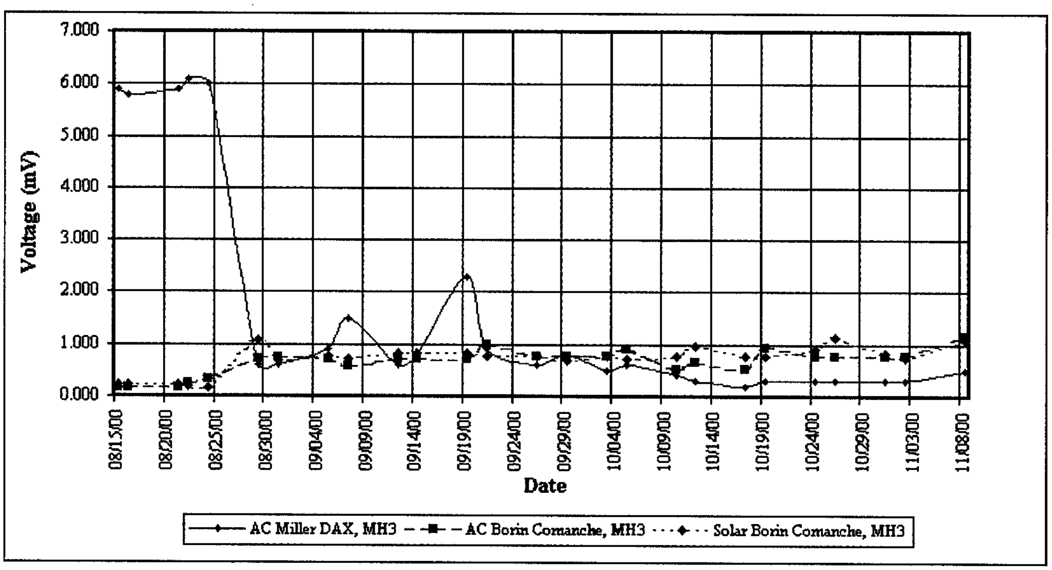

Figure 29. Voltage measured across rectifier shunt at Machine House 3 (measurements taken remotely at CERL).

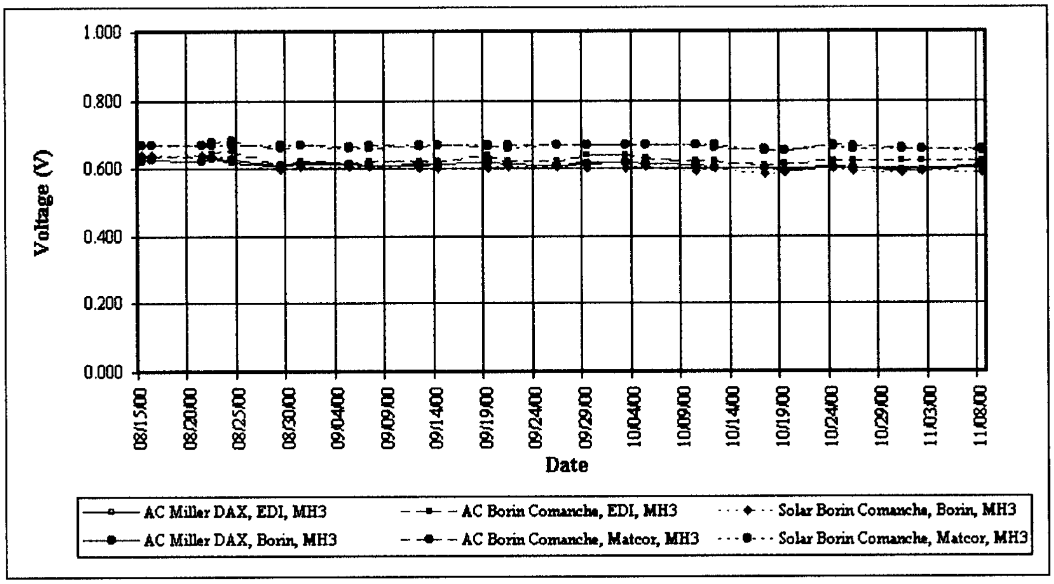

Figure 30. On potential of Gate 3 vs silver / silver chloride reference cell (measurements taken remotely at CERL).

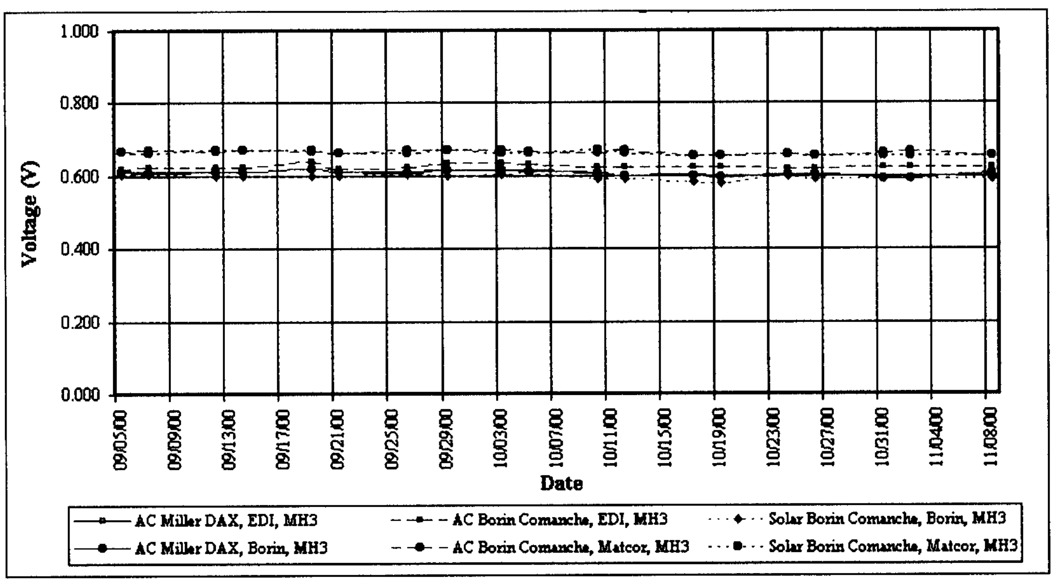

Figure 31. IOP of Gate 3 vs silver / silver chloride reference cell (measurements taken remotely at CERL).

Results: M.C. Miller DAX

The field data comparing the onsite and remote readings obtained during the September site visit are shown in Table 15 and Table 16 The data indicate that the equipment is accurate for structure-to-earth potentials and rectifier voltage reading.

Table 15. Comparison of remote and onsite measurements for solar-powered M.C. Miller DAX at Canaveral Lock Machine House 1 (19 September 2000).

Measurement	Remote Data	Onsite Data
Rectifier Voltage	3.05 volts	3.06 volts
Voltage Across Rectifier Shunt and Calculated Current*	8.5 millivolts (0.85 A)	8.2 millivolts (0.82 A)
Matcor Reference: On Potential	0.65 volt	0.65 volt
Matcor Reference: Instant Off Potential	0.65 volt	0.64 volt
EDI Reference: On Potential	0.67 volt	0.67 volt
EDI Reference: Instant Off Potential	0.66 volt	0.67 volt

*The current in parentheses was calculated using the shunt rating of 50 millivolts= 5 Amps.

Table 16. Comparison of remote and onsite measurements for AC-powered M.C. Miller DAX at Canaveral Lock Machine House 3 (19 September 2000).

Measurement	Remote Data	Onsite Data
Rectifier Voltage	16.84 volts	16.83 volts
Voltage Across Rectifier Shunt and Calculated Current*	0.8 millivolts (80 mA)	0.0 millivolts (0 A)
Borin Reference: On Potential	0.60 volt	0.61 volt
Borin Reference: Instant Off Potential	0.60 volt	0.61 volt
EDI Reference: On Potential	0.60 volt	0.61 volt
EDI Reference: Instant Off Potential	0.60 volt	0.61 volt

*The current in parentheses was calculated using the shunt rating of 50 millivolts= 5 Amps.

As was the case with the Borin units, the DAX current output data were not completely accurate for extremely low (less than one millivolt) readings of rectifier current output shunts. As noted above, this current-measurement inaccuracy would not be unexpected from an RMU when a CP system malfunctions and current drops to near-zero. Since the CP system malfunctioned throughout the entire test, however, it is unknown how accurate the M.C. Miller units would be under normal CP system operating conditions.

The data measured remotely at CERL for the DAX units are shown in the plots for Machine House 1 and Machine House 3 in Figure 28 through Figure 35. The measurements are in line with those from the other RMUs and the results from the September site survey.

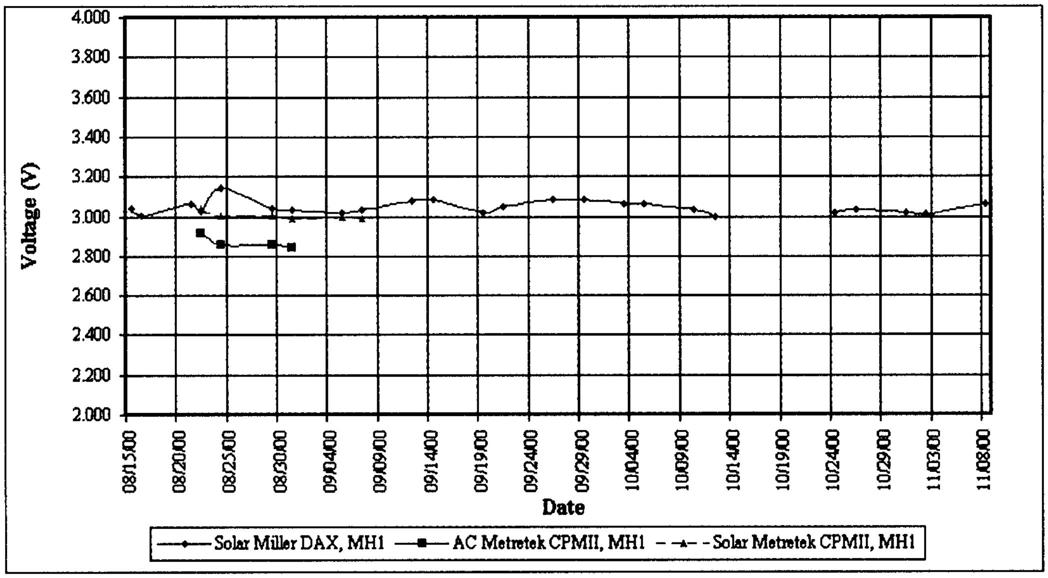

Figure 32. Rectifier output voltage at Machine House 1 (measurements taken remotely at CERL).

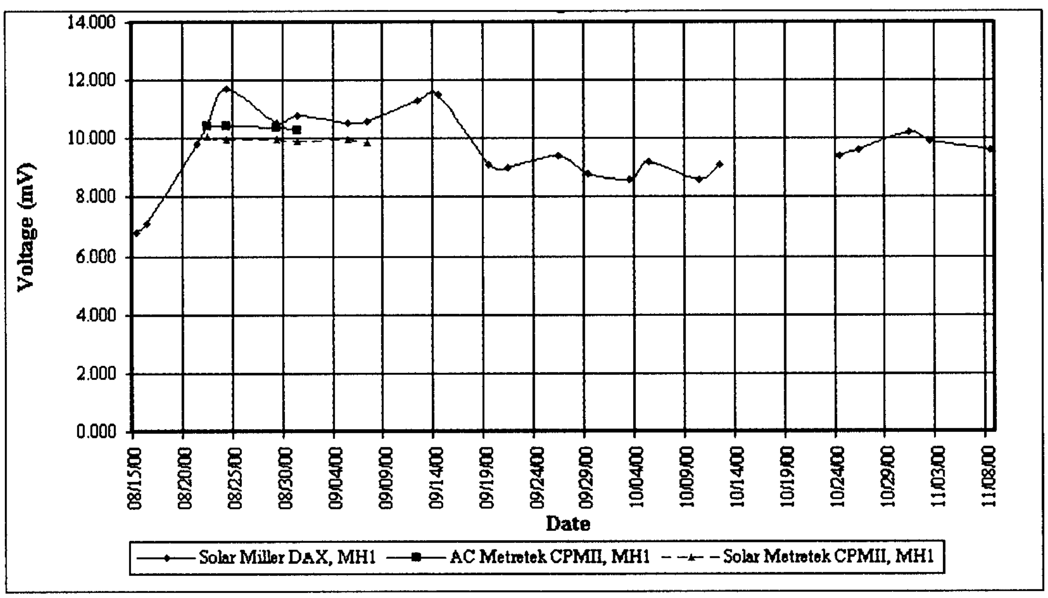

Figure 33. Voltage measured across rectifier shunt at Machine House 1 (measurements taken remotely at CERL).

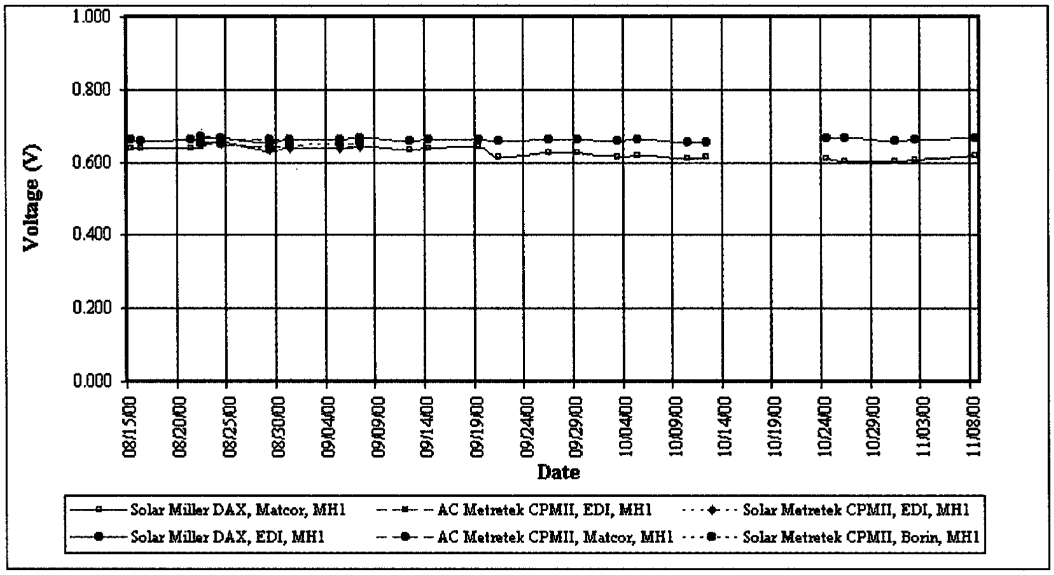

Figure 34. On potential of Gate 1 vs silver / silver chloride reference cell (measurements taken remotely at CERL).

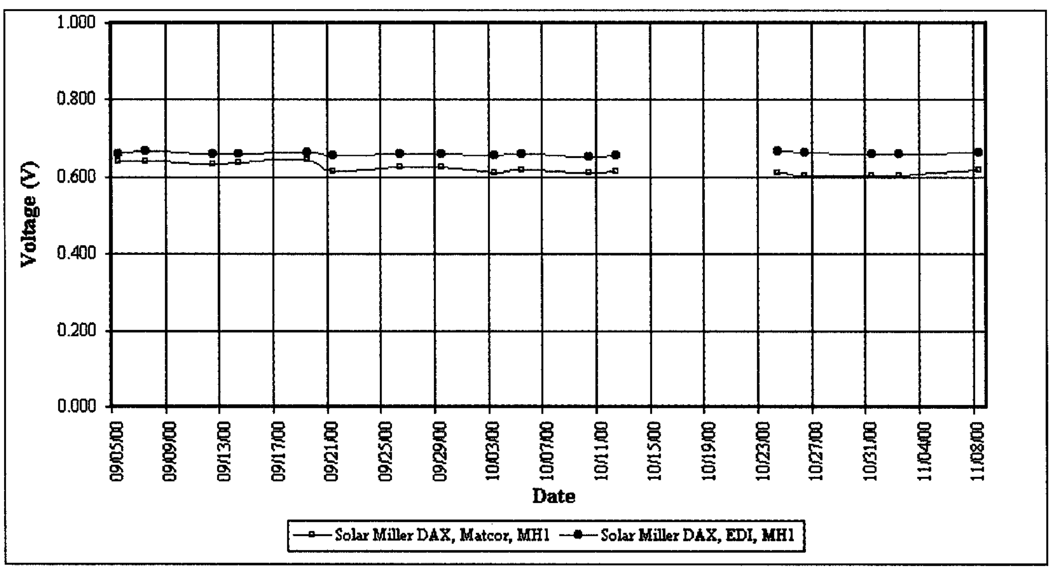

Figure 35. IOP of Gate 1 vs silver / silver chloride reference cell (measurements taken remotely at CERL).

Results: Metretek CPM-II

The field data comparing the onsite and remote readings obtained during the September site visit are shown in Table 17 and Table 18. The data indicated that the equipment is accurate, but structure-to-earth IOPs could not be obtained because of the technical problems described previously.

Table 17. Comparison of remote and onsite measurements for solar-powered Metretek CPM-II at Canaveral Lock Machine House 1 (19 September 2000).

Measurement	Remote Data	Onsite Data
Rectifier Voltage	3.08 volts	3.09 volts
Voltage Across Rectifier Shunt and Calculated Current*	8.3 millivolts (0.83 A)	8.3 millivolts (0.83 A)
EDI Reference: On Potential	0.68 volt	0.68 volt
EDI Reference: Instant Off Potential	no data	no data
Borin Reference: On Potential	0.64 volt	0.64 volt
Borin Reference: Instant Off Potential	no data	no data

*The current in parentheses was calculated using the shunt rating of 50 millivolts = 5 amps.

Table 18. Comparison of remote and onsite measurements for AC-powered Metretek CPM-II at Canaveral Lock Machine House 1 (19 September 2000).

Measurement	Remote Data	Onsite Data
Rectifier Voltage	2.90 volts	3.07 volts
Voltage Across Rectifier Shunt and Calculated Current*	10.2 millivolts (1.02 A)	8.3 millivolts (0.83 A)
Matcor Reference: On Potential	0.66 volt	0.66 volt
Matcor Reference: Instant Off Potential	no data	no data
EDI Reference: On Potential	0.64 volt	0.65 volt
EDI Reference: Instant Off Potential	no data	no data

*The current in parentheses was calculated using the shunt rating of 50 millivolts = 5 amps.

The data measured remotely at CERL for the Metretek units are shown in the plots for Machine House 1 in Figure 32 through Figure 35. As reported previously, data could only be obtained from the Metretek units during approximately 3 weeks of the evaluation period. Cellular communication problems made it impossible to collect data remotely during the rest of the evaluation.

Step 8: Analysis of Results and Ranking of RMUs

A matrix approach was developed to rank the RMUs according to the evaluated features.

Weighting factors were assigned to each software feature based on its overall importance. For each feature, the software packages were graded between 1 and 5 (5=excellent, 4=very good, 3=good, 2=acceptable, 1=unacceptable). The score was determined by multiplying the grade (rating) times the weighting factor.

The software ratings and scores are summarized in Table 19. The maximum possible software score was 300 and the minimum possible software score was 60.

Table 19. Software evaluation matrix.

Feature	Weighting Factor	Comanche (Borin)		DAX (M.C. Miller)		CPM-II (Metretek)	
		Rating	*Score*	*Rating*	*Score*	*Rating*	*Score*
Software manual	5	2	10	3	15	3	15
Software manual (novices)	4	2	8	3	12	3	12
Software manual (experts)	2	3	6	3	6	3	6
Technical support (software)	5	4	20	5	25	2	10
Toll-free number	2	3	6	3	6	1	2
Software operation	5	4	20	5	25	3	15
Software loading	1	2	2	4	4	3	3
Software configuration	2	2	4	5	10	3	6
Software versatility	5	4	20	4	20	2	10
Software appearance	2	3	6	4	8	3	6
Help function	2	2	4	4	8	3	6
Ease of operation (single unit)	2	3	6	4	8	3	6
Ease of operation (multiple units)	4	3	12	3	12	1	4
Data report format	3	4	12	4	12	3	9
Exportability to MS Excel or equal	4	4	16	4	16	4	16
Spreadsheet formatting	2	4	8	4	8	4	8
Capability to support alarms	5	3	15	3	15	3	15
Capability to support synchronized interruption	5	3	15	3	15	3	15
Software Score			190		225		164

A similar scheme was used to rank the hardware features. The maximum possible hardware score was 400 and the minimum possible hardware score was 80. The hardware and software scores were added together to give an overall score. The maximum possible overall score was 700 and the minimum possible overall score was 140. The hardware ratings and overall scores are summarized in Table 20.

Results: Borin Comanche

The software score for the Borin Comanche was 190, and the hardware score was 258, for a total score of 448.

The short-term evaluation conducted during this project indicates that the system is technically adequate. The system's long-term operating characteristics cannot be verified until systems have been in place for an extended period of time.

Table 20. Hardware evaluation matrix.

Feature	Weighting Factor	COMANCHE (Borin)		DAX (M.C. Miller)		CPM-II (Metretek)	
		Rating	*Score*	*Rating*	*Score*	*Rating*	*Score*
Hardware manual	5	2	10	3	15	2	10
Ease of installation	10	3	30	4	40	2	20
Ease of cellular communication	3	3	9	4	12	1	3
Reliability of solar power*	4	4	16	4	16	3	12
Technical support (hardware)	5	5	25	5	25	1.5	7.5
Interrupter relay	8	1	8	1	8	2	16
Data accuracy*	10	4	40	4	40	3	30
Accuracy of simultaneous operation	10	3	30	3	30	1	10
Reliability*	10	4	40	4	40	2	20
Surge/lightning protection	5	3	15	3	15	3	15
Versatility	5	4	20	4	20	1	5
Remote programming	5	3	15	4	20	2	10
Hardware Score			258		281		158.5
Software Score (Table 1)			190		225		164
OVERALL SCORE			448		506		322.5

* Note that results for these criteria are based on short-term evaluation only.

The system was difficult to install and configure. Borin did not provide a relay for interrupting the rectifier current for IOP measurements.

The software is difficult to use, but is powerful and has great flexibility in operation of the remote monitoring systems.

Many of the problems that occurred with this system could have been avoided by requiring onsite assistance from the manufacturer during hardware and software installation and configuration, or by requiring the manufacturer to perform a turn-key installation.

The system works with solar power and cellular communications. As discussed on pages 61 and 61, some caution may be warranted when selecting computers (and operating systems) that will be used for contacting the RMUs; the evaluated version of Borin software presented difficulties for computers running Windows NT and did not support the use of COM3 and COM4 ports. The manufacturer reports that a newer version of the software solves these problems, but the update was not available for CERL to evaluate during this study.

Results: M.C. Miller DAX

The software score for the M.C. Miller DAX was 225, and the hardware score was 281, for a total score of 506.

The short-term evaluation conducted during this project indicates that the system is technically adequate. The system's long term operating characteristics cannot be verified until systems have been in place for an extended period of time.

The hardware was relatively simple to install onsite. The only problem was the lack of an adequate relay for interrupting the rectifier current for IOP measurements.

The software was simple to install and configure and required no assistance from the manufacturer. The software is powerful and has excellent flexibility in the operation of the remote monitoring systems.

The system works with solar power and cellular communications. However, it is prudent to verify the availability of cellular service and the suitability for effective solar power at specific locations before selecting these units for use. No special computers or additional external devices are required for communication with the remote monitoring systems.

The primary disadvantage of this remote monitoring system is that the tested hardware is no longer available due to supply problems with the equipment's microprocessor. Replacement hardware is under development and should be evaluated once it is available.

Results: Metretek CPM-II

The software score for the Metretek CPM-II was 164, and the hardware score was 158.5, for a total score of 322.5.

The short-term evaluation conducted during this project indicates that the tested system may be technically acceptable for some limited applications. Applications that require either solar power operation or cellular communications should be avoided until the problems described previously are resolved. Previous evaluations of this equipment (Van Blaricum et al. 1998) indicated that it does operate properly with landline phone communication and AC power.

Additionally, IOP data could not be obtained from the units during this test. It is interesting to note that units from this company were able to obtain IOP readings during a previous evaluation (Van Blaricum et al. 1998).

The hardware is somewhat difficult to install but the software is relatively easy to install and configure. The remote monitoring system has significant limitations in its operation, and its need for a dedicated computer that is constantly available for the onsite hardware to contact is a substantial disadvantage. The large, heavy proprietary external modem is also a disadvantage. The significant limitations and special requirements of this remote monitoring system makes the equipment difficult and cumbersome to use.

6 Lessons Learned: Selection and Implementation Guidance

Remote monitoring is a promising technology for helping the Army Corps of Engineers establish and maintain a strong CP monitoring program which will help to increase the life cycle of civil works structures. However, as stated in Chapter 1, there are some challenges in implementing this technology effectively. Some important lessons were learned during this evaluation, and they are essential to the successful application of this technology at Corps sites. It is hoped that RMU manufacturers may gain insights from this study that will help them continue to improve their products.

Lesson 1: Specify a Turnkey Installation

In general, local electrical contractors or in-house personnel *should not* be used to install RMU equipment. At this point, typical contractors and shop personnel do not have sufficient experience with such technology to sort out the inevitable difficulties that may be expected.

In most cases, it would be advisable to hire the RMU manufacturer to perform a turnkey system installation. The manufacturer should be required to provide, install, and completely configure the RMUs and the associated software. It would also be a good idea to include a training session for site personnel to show them how to operate the software and perform common tasks. Proper system operation should be verified and documented before the Corps accepts the system. Sites that do not have personnel qualified to perform system maintenance and repairs should consider purchasing a service agreement to ensure that the equipment continues to function properly over the long term. Costs for a service agreement will vary depending on the number of RMUs covered and the level of service specified.

An exception to this general guidance may be considered if in-house personnel or contractors have extensive experience with wiring, installing, and programming remote monitoring systems. Even in such cases it may be necessary or advisable to obtain training or onsite assistance directly from the manufacturer for the first few RMU installations. Even if electricians have experience with installing CP systems, they may not be able to install RMUs without significant guidance. Loftus Electric has experience with installing CP systems and they have previously worked very successfully with the system at Canaveral Lock. Their work in installing the electrical conduit leading to the RMUs was generally of good quality, but they did not have experience installing CP RMUs. This led to difficulties, delays, confusion, and frustration during the installation.

One of the biggest problems encountered was that the manufacturers installation manuals did not provide detailed wiring diagrams. The electricians on this project, through little fault of their own, were unable to work from the written descriptions of what should be done. The results were polarity reversals in the power supply, burned out data channels, missing power leads, improperly configured communication devices, and faulty or missing relay wiring.

A related problem was that some of the procedures were poorly documented in the text of the manuals, leaving the user with some doubt as to which set of procedures should be followed for the desired configuration. Consultation with the manufacturer was required to interpret some of the instructions in the manuals and to resolve some of the questions and uncertainties.

The cost of a complete turnkey installation for one RMU system similar to those installed at Canaveral Lock is estimated to be approximately \$500 – \$1000 plus travel and *per diem* costs.

Lesson 2: Details are Important When Selecting an RMU

Technology and products are changing rapidly in the area of CP remote monitoring. New companies are entering the market, and RMU systems are constantly being changed and improved. The following are some general guidelines that potential buyers should consider when selecting a system.

Backup Battery

All CP RMUs should be supplied with a backup battery. The manufacturer should provide a backup battery that will provide power for a reasonable amount of time in the event of a power outage. If the RMU communicates by cellular phone, the battery should also be adequate to power the cellular transceiver for at least one trouble call to the master computer.

Surge Protection

All CP RMUs should be equipped with surge protection on all inputs and outputs, including phone lines, data channels, and the power supply.

Quality of Components

All CP RMUs should be built with industrial-grade solid state components.

Full Differential Channels

The term *full differential channels* means that each data channel has its own positive and negative terminal. This feature is essential in applications where the RMU is being used to monitor electrically isolated structures.

Alarms

RMUs with alarm capabilities will notify the user automatically if a measurement falls outside the range that has been specified for it. Alarms are considered to be a beneficial feature, especially for critical structures. Alarms may be implemented differently in the various RMUs. If you are interested in using the alarm feature, you may want to ask the following questions of the manufacturer:

- Does the RMU call the user every single time a measurement falls outside of the specified range, or does it wait until two or more consecutive off-spec measurements are made? Can the user select the number of off-spec measurements that are allowed before the RMU places an alarm call?

- Does the system require a dedicated computer and telephone line to receive alarm calls from the RMU?

- What does the RMU do if it attempts to call in an alarm and there is no answer? What happens if it gets a busy signal?

- Can the software be set up to call additional phone numbers after it has unsuccessfully attempted to report an alarm to the primary number?

Synchronized Rectifier Interruption

This feature enables the RMU to interrupt several rectifiers at exactly the same instant. This feature is essential for accurate IOP readings if the structure is protected by more than one rectifier. If the structure is protected by only one rectifier, this feature is not necessary.

Ability to Program RMUs Remotely

This is a very convenient feature that allows the user to change RMU settings without visiting the site. This feature is virtually a must for situations where the master computer is located a long distance from the monitoring site.

Software

During this evaluation it was observed that software versatility and ease of use can vary widely between different remote monitoring systems. These factors should be scrutinized closely during the equipment selection process. If possible, demonstration or evaluation copies of software should be obtained from the manufacturer and reviewed before making a purchase decision.

Different users will have different software needs. For example, large, complex networks of CP systems will require powerful, versatile software. Simple, less sophisticated software may be adequate for smaller CP systems. Consideration should also be given to the end user of the software. A complex, feature-filled software package may completely befuddle a novice RMU user but be exactly right for an experienced power user. Conversely, a power user may become frustrated by the limitations of a simple software package.

Level of Comfort With the Manufacturer

This issue is extremely important because the user will very likely need technical support from the manufacturer at some point. Be sure that you understand and feel comfortable with the manufacturer's technical support policy and capabilities. If possible, talk to some of the company's customers. Some issues to consider discussing:

- Types and costs of technical support plans available: Is there a plan that closely matches your needs?
- Experience level of technical support personnel: How long have they been working with the product? How much experience do they have with troubleshooting problems over the phone and in the field?

- Accessibility of support personnel: How long does it usually take to get in contact with knowledgeable support personnel? Is a toll-free number available? If a key support person is out of the office, is a backup available?

- Timeliness: How long does it usually take to get a problem solved once it has been reported? Are replacement parts readily available if something breaks?

Cost

The main guideline here is to make sure you understand what needs to be purchased in addition to the basic RMU. For example, one of the systems tested requires the user to purchase a proprietary modem for the master computer. Other 'extra' items may include software, relays to interrupt the CP current, cellular phone transceivers, and solar power equipment.

Lesson 3: Know Your Site and Specify Carefully

Most RMUs are custom-manufactured for each application, so it is very important to have detailed information about the site where they will be installed. The manufacturer will generally ask for details about your CP system and the measurements that you wish to make before preparing a price quotation. It is a good idea to have this information in hand before talking to the manufacturer. A person who is knowledgeable about CP systems should visit the site where the RMU is to be installed and get answers to the following general questions:

1. What is the input voltage of the rectifier?
2. Will the RMU be required to monitor the input voltage of the rectifier?
3. What is the maximum rated output voltage and current of the rectifier?
4. How many circuits does the rectifier have?
5. Will the RMU be required to monitor the output voltage(s) of the rectifier? If so, how many circuits will be monitored?
6. Will the RMU be required to monitor the output current(s) of the rectifier? If so, how many currents will be monitored? For a CP rectifier with multiple circuits, some users may wish to monitor the total current output, but others may wish to monitor the current output of each individual circuit. Measuring the total current output is less expensive because only one data channel is required, but, problems with individual rectifier circuits may remain undetected.
7. Are there shunts available to conduct the current measurements? (If not, shunts will be needed).

8. Where are the shunts for measuring the rectifier current located: positive or negative side? (This is very important to the operation of some RMUs.)
9. Will structure "on" potentials be measured? If so, how many?
10. Will structure IOPs be measured? If so, do you wish to locate the relay in the AC input or the DC output of the rectifier?
11. How will the RMUs be powered?
12. How will the RMUs communicate with the master computer (e.g., cellular phone or landline)?
13. What type of environment will the RMUs be required to withstand (e.g., high humidity, high salinity, extreme temperatures, etc.)?
14. What types of enclosures and mounting hardware are needed? Are locks required to prevent unauthorized people from tampering with the equipment?

Some manufacturers may require information in addition to these items. If the manufacturer asks a question about the CP system(s) that you do not understand, always ask for clarification. Clear communication between everyone involved can prevent problems, delays, and costly surprises.

Many people will find it helpful to take detailed photographs of the site and the CP equipment. Photographs can be used to help the manufacturer and others involved in the project understand the site. They can also be used as a record of CP system details in case there are questions. A high-resolution digital camera is especially helpful for this because image-viewing software can be used to zoom in on specific details as needed.

Some sites may find it useful and worthwhile to hire an expert consultant (such as a licensed corrosion engineer) to assist in preparing the ordering specifications, especially if a large number of systems are to be purchased.

CP systems and RMUs tend to vary widely, so it is very important to work closely with the manufacturer to make sure that they understand your specific requirements. Even if you have had detailed discussions with the manufacturer, make sure that your ordering specifications spell out all of the details *in writing*. Do not simply give the RMU's model number on the order and assume that the details will be handled according to previous discussions.

Lesson 4: Be Aware of Cellular Phone Problems and Issues

The use of cellular telephones for communication between the RMUs and the master computer may be a viable option over the long term for locations where installing a landline would be difficult or expensive, or where cellular service is less expensive than standard telephone service. However, there are some short-term problems and issues related to the industry's transition from analog to digital cellular service. Specific problems encountered during the current evaluation were are explained in Chapter 5. These types of problems may make cellular communication an unwise choice for some situations into the near future.

If cellular communication is being considered, the following general issues should be investigated carefully before a decision is made.

Availability of RMUs with Digital Modems

The entire cellular telephone industry was transitioning to digital service at the time of this evaluation, but all of the RMU manufacturers were still using analog cellular modems. It is hoped that the next generation of RMUs will incorporate digital cellular communication capabilities. Since it is unknown exactly when such RMUs will become available, potential buyers of cellular RMUs should discuss this issue with the manufacturers before making a purchase. Buyers should purchase RMUs with digital cellular modems, if feasible.

Quality and Reliability of Cellular Service

Until RMUs with digital cellular modems become available, users will have to obtain cellular service from local providers because the national providers have stopped offering analog service. Quality, reliability, and types of contracts available may vary widely between local providers. It is wise to investigate all the options available in a given area before making a decision.

Avoid service plans that require phones to be reactivated if they are not used for a few days. You may wish to speak with other customers of the providers being considered and ask them questions about the availability, quality and timeliness of customer service, and frequency of problems making or receiving calls (such as busy circuits or dropped calls). All of these issues created problems during this evaluation.

Ability of Cellular Provider to Do Business Outside Local Calling Area

Most local carriers used during this evaluation were not set up to do business with customers located outside of their service area. This problem can cause delays, frustration, and extra work for everyone involved.

One problem was that the local carriers required that the RMU modems be activated in the same area code in which they would be used. This requirement makes it impossible for a manufacturer located outside the CP site area code to completely program and configure the RMUs at the factory. This problem can be avoided by requiring the manufacturers to provide a turnkey installation, as recommended previously. Options for more experienced RMU users might include contracting the manufacturer to provide onsite assistance during installation or to provide detailed written or verbal instructions for the users to perform the configuration themselves.

Another issue was that some local carriers required a local billing address, a local point of contact, and a credit check before they would activate cellular service. This resulted in significant problems and delays. This problem can be avoided by having the local installation prepare the contract for cellular service.

Lesson 5: Use Care in Specifying Solar-Powered Systems

One of the objectives of this evaluation was to test equipment that would be suitable for remote sites, so it was decided to test solar-powered RMUs. The original intent of the project was to test the solar-powered RMUs at a remote site where AC power was not readily available and where the CP system was the sacrificial (galvanic) type. The project budget did not allow the installation of a second test site, so the solar units were tested at the Canaveral Lock site.

Solar power may be a viable alternative for some sites, such as remote areas where AC power is not readily available, but the cost of some of the manufacturers' solar-powered systems may be too high to justify their use. Solar-powered systems should be selected carefully, with special attention given to the issues discussed below.

It was found that most RMU manufacturers had very little experience with solar panels and batteries even though all of them claimed that their equipment could be configured for solar operation. The sizes of the solar panels and batteries supplied varied greatly between the three manufacturers.

The most important consideration for solar power systems is to make sure that they provide enough power for proper and continuous operation of the RMU. Problems encountered with the Metretek solar panel are described in Chapter 5.

Costs also tended to vary widely. It is interesting to note that the most expensive and the least expensive solar panels worked well, while the medium-priced panel failed to provide adequate power.

Check with the manufacturer to make sure that all components associated with the RMU can be solar-powered. For example, Borin's cellular phone transceiver could not be operated with solar power at the time of this evaluation.

The purchase order should very clearly specify that the RMU and associated components are to be solar powered. Some RMUs require significant modifications to enable them to use solar power, and it is difficult and costly to retrofit such units once they have been built.

Lesson 6: Understand the Ancillary Site Design and Coordination Issues

As described in Chapter 4, some errors were made in the original test site design, and this caused a number of delays. The design had to be revised several times to keep costs within the project budget and to avoid problems such as the buildup of silt inside the reference cell shields. The guidance below will help potential RMU users avoid similar problems.

The RMUs and reference cells should be located to minimize the amount of electrical conduit that needs to be mounted. Mounting electrical conduit within the lock chamber was the most expensive part of installing the equipment in this project. Existing conduit should be used if it is feasible to do so. Even if existing conduit can be used, however, the installers will need to spend some time working in the lock chamber to route wires and hang the reference cells. If possible, this work should be scheduled during times when the locks are closed for maintenance or repair. If this is not possible, the installers should be made aware that they may need to suspend work during the opening and closing of the locks. Significant delays can arise when lock traffic is heavy and the gates are operated frequently, though, so the installers should be informed of lock schedules and times of expected heavy traffic so they can plan their work accordingly.

Permanent reference cells should be mounted close enough to the protected structure to provide a meaningful reading, but they must be located so they do not interfere with the opening and closing of the gates. The locations finally used in this project worked well. See Figure 9 and Figure 12 for details.

Reference cells should be equipped with protective shields that permit silt to escape, as shown in Figure 10 and Figure 11. If possible, the brackets and other mounting hardware for the reference cells should be located above the water line at low tide so divers are not needed to perform the installation. We found that the use of certified divers would have added significantly to the cost and would have required the preparation of additional paperwork.

Items such as mounting brackets, screws, and other hardware required for installing the RMUs should be specified carefully. The designer should specify materials that are able to withstand local environmental conditions, and should be aware of which materials, sizes, etc., are readily available locally. The designer may wish to specify alternatives in case the most desirable materials and components cannot be obtained without long delays or excessive cost. For example, it was initially planned to use Type 316 stainless steel for all of the hardware, but this alternative would have been very costly and there would have been a delay of several weeks required to obtain all of the necessary components. Consequently, the prices and availability of coated steel and Type 304 stainless steel were investigated, and the latter material was eventually selected and installed.

Timing is another issue that should be addressed. The building and shipping of the remote monitoring equipment took approximately 2 to 4 months from the time that complete specifications were provided to the manufacturers. Installation of the RMUs should be planned and scheduled accordingly.

7 Conclusions

Three different commercially available CP remote monitoring systems were subjected to a short-term field test at Canaveral Lock, FL. The evaluation included both AC-powered systems and solar-powered systems. The use of cellular phones for communication between the remote units and the master computer was also evaluated.

Two of the systems were found to be accurate and technically acceptable for general civil works use. It was found that the third system may be acceptable for some limited applications.

The systems varied widely in terms of ease of installation, ease of use, and software versatility and user-friendliness. Because of the difficulties encountered during the installation and setup of the systems, it was concluded that most buyers should consider purchasing a turnkey installation from the system manufacturer before attempting to execute an installation with staff or local contractors.

Solar power worked successfully for two of the three systems tested.

The industrywide changeover from analog to digital cellular telephone service was still in progress during this evaluation, and this situation caused some problems in procuring remote telecommunication services. It is hoped that this problem will become moot in the near future as RMU manufacturers redesign their systems to operate with digital modems.

Three different commercially available permanent reference cells also were field-tested and all three performed accurately during the demonstration period. Evaluation of long-term stability and accuracy would require a longer test period.

The experience gained and lessons learned from this evaluation were compiled and documented to help future buyers of this technology avoid common mistakes and pitfalls in equipment selection, site design, and procurement.

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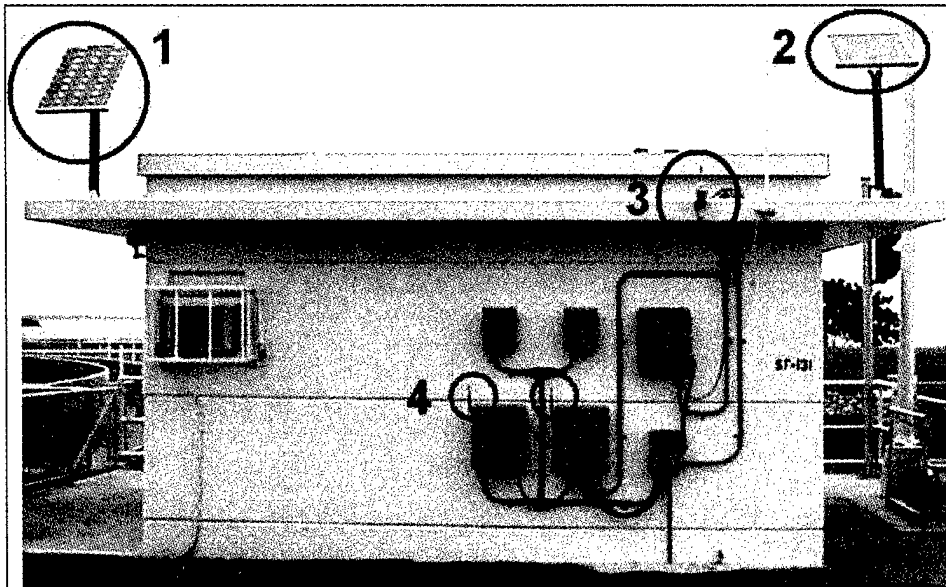
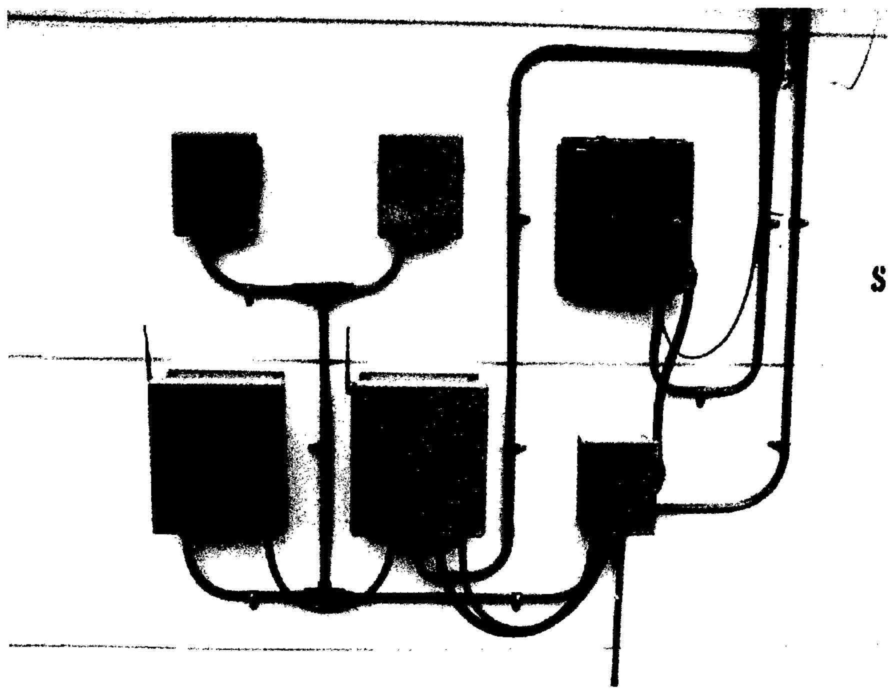
Appendix: Detailed Site Layouts



MACHINE HOUSE 1 LAYOUT (OVERALL)

1. M. C. Miller DAX Solar Panel
2. Metretek CPM-II Solar Panel
3. M. C. Miller DAX Solar-Powered Digital Modem Antenna
4. Metretek CPM-II Digital Modem Antennas

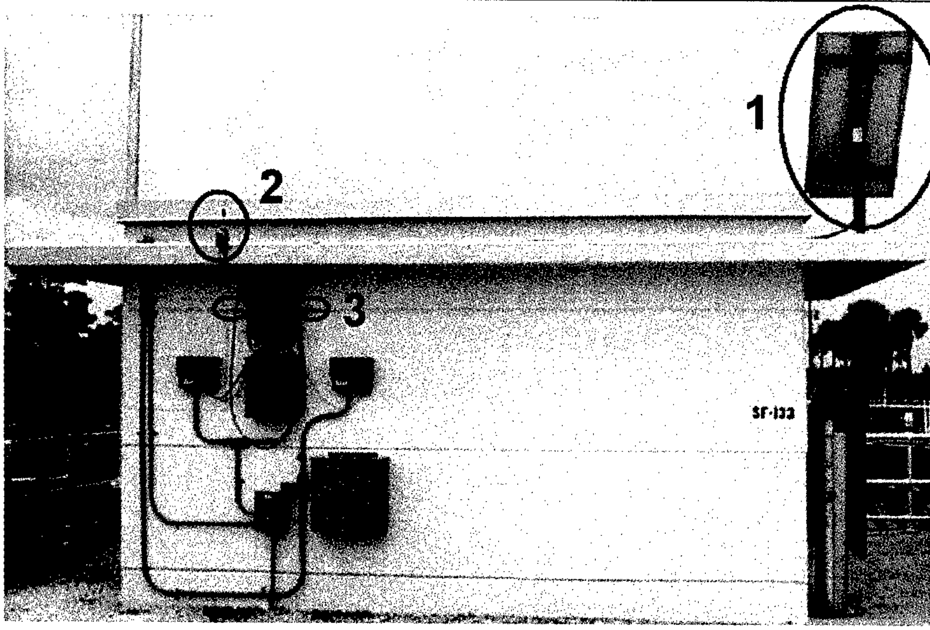
USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT		
CP REMOTE MONITORING UNITS INSTALLED AT CANAVERAL LOCK - MACHINE HOUSE 1 LAYOUT		
SCALE:	NONE	Champaign, Illinois
DESIGNED BY:	WRN	
DATE:	11 August 2000	
DRAWING No.:	MHOUSE1-001	



MACHINE HOUSE 1 LAYOUT (RMUs)

1. Relay Switch for AC-Powered Metretek
2. Relay Switch for Solar-Powered Metretek
3. M. C. Miller DAX, Solar Powered
4. Metretek CPM-II, AC Powered
5. Metretek CPM-II, Solar Powered
6. Terminal Strips with Connections

USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT		
CP REMOTE MONITORING UNITS INSTALLED AT CANAVERAL LOCK - MACHINE HOUSE 1 LAYOUT		
SCALE:	NONE	
DESIGNED BY:	WRN	
DATE:	11 August 2000	
DRAWING No.:	MHOUSE1-002	Champaign, Illinois

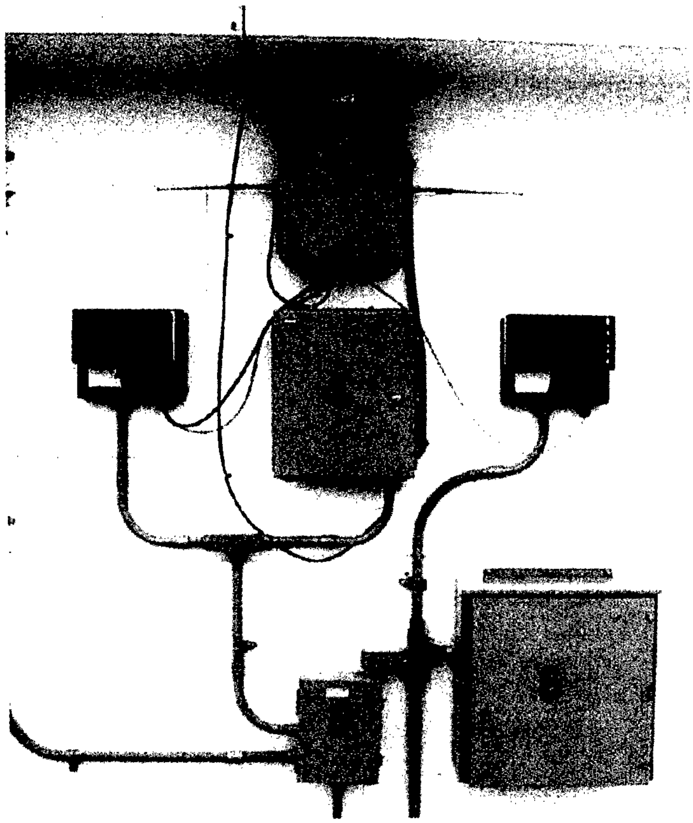


MACHINE HOUSE 3 LAYOUT (OVERALL)

1. Borin Comanche Solar Panel
2. M. C. Miller DAX AC-Powered Digital Modem Antenna
3. Borin Comanche Digital Modem Antennas

USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT	
CP REMOTE MONITORING UNITS INSTALLED AT CANAVERAL LOCK - MACHINE HOUSE 3 LAYOUT	
SCALE:	NONE
DESIGNED BY:	WRN
DATE:	11 August 2000
DRAWING No.:	MHOUSE3-001

Champaign, Illinois

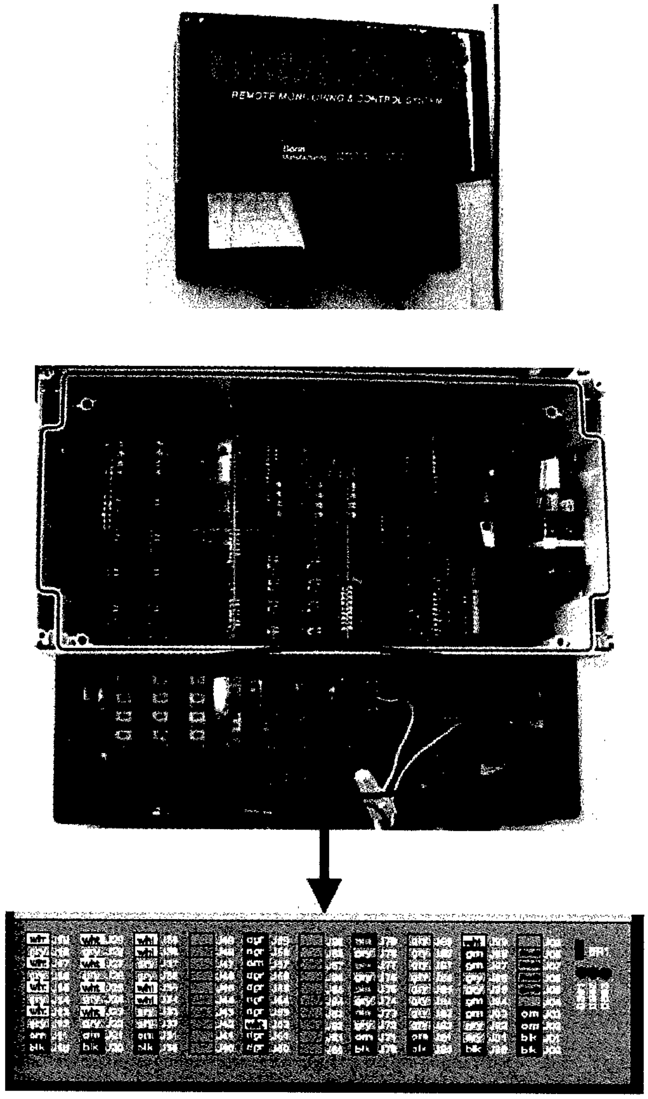


MACHINE HOUSE 3 LAYOUT (RMUs)

1. Transceivers, Antennas and Power Supplies for Borin Comanche Units
2. Borin Comanche, AC-Powered
3. Borin Comanche, Solar-Powered
4. M. C. Miller DAX, AC Powered
5. Terminal Strips with Connections
6. Battery and Power Connection for Solar Powered Borin Comanche

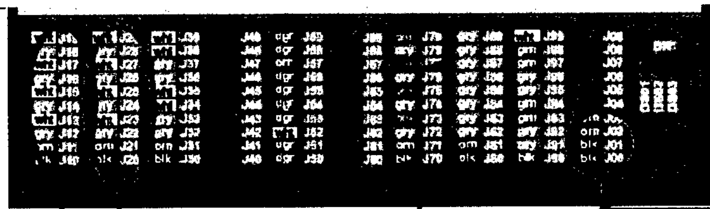
USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT	
CP REMOTE MONITORING UNITS INSTALLED AT CANAVERAL LOCK - MACHINE HOUSE 3 LAYOUT	
SCALE:	NONE
DESIGNED BY:	WRN
DATE:	11 August 2000
DRAWING No.:	MHOUSE3-002

Champaign, Illinois



USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT		
BORIN COMANCHE DAX WIRING DIAGRAM INSTALLED AT CANAVERAL LOCK - UNIT SCHEMATIC		
SCALE:	NONE	Champaign, Illinois
DRAWN BY:	WRN	
DATE:	14 August 2000	
DRAWING No.:	BCOM-001	

Borin Camanche Jumper Settings (Part 1)



	wht	J19
	gry	J18
	wht	J17
	gry	J16
SHUNT (8) (+)	wht	J15
SHUNT (8) (-)	gry	J14
RECTIFIER (8) (+)	wht	J13
RECTIFIER (8) (-)	gry	J12
	orn	J11
	blk	J10

	wht	J29
	gry	J28
	wht	J27
	gry	J26
MATCOR REF. (+)	wht	J25
STRUCTURE (-)	gry	J24
EDI REF. (+)	wht	J23
STRUCTURE (-)	gry	J22
	orn	J21
	blk	J20

POWER IN FOR RELAY	blu	J79
TO RELAY	gry	J78
POWER IN (+)	orn	J03
POWER IN (+)	orn	J02
POWER IN (-)	blk	J01
POWER IN (-)	blk	J00

BORIN COMANCHE - MACHINE HOUSE 1
LEFT SIDE FACING RMUs, AC POWER
SN: 9908202

	wht	J19
	gry	J18
SOLAR (+)	wht	J17
GROUND (-)	gry	J16
SHUNT (8) (+)	wht	J15
SHUNT (8) (-)	gry	J14
RECTIFIER (8) (+)	wht	J13
RECTIFIER (8) (-)	gry	J12
	orn	J11
	blk	J10

	wht	J29
	gry	J28
	wht	J27
	gry	J26
MATCOR REF. (+)	wht	J25
STRUCTURE (-)	gry	J24
BORIN REF. (+)	wht	J23
STRUCTURE (-)	gry	J22
	orn	J21
	blk	J20

POWER IN FOR RELAY	blu	J79
TO RELAY	gry	J78
POWER IN (+)	orn	J03
POWER IN (+)	orn	J02
POWER IN (-)	blk	J01
POWER IN (-)	blk	J00

BORIN COMANCHE - MACHINE HOUSE 1
RIGHT SIDE FACING RMUs, SOLAR POWER
SN: 9908201

USACERL - ERDC
CANAVERAL LOCK - CP RMU PROJECT

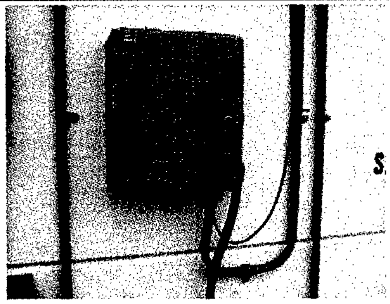
BORIN COMANCHE DAX WIRING DIAGRAM
INSTALLED AT CANAVERAL LOCK - UNIT SCHEMATIC

SCALE:	NONE
DRAWN BY:	WRN
DATE:	14 August 2000
DRAWING No.:	BCOM-002

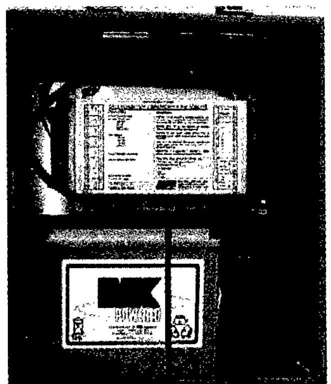
Champaign, Illinois

Borin Camanche Jumper Settings (Part 2 - Details)

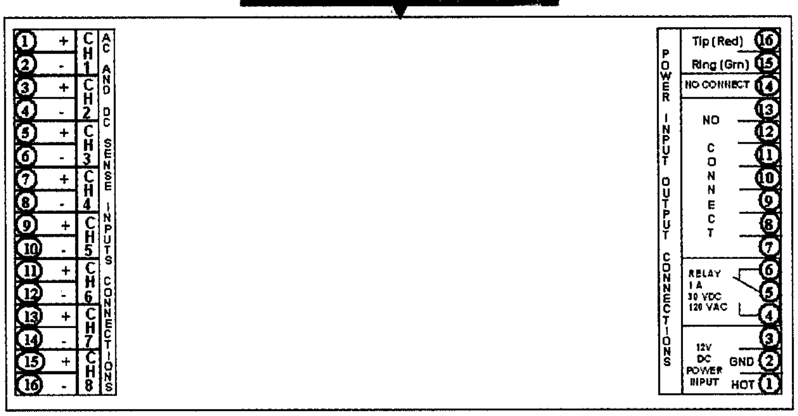
Miller DAX Units
Machine House 3:
AC-Powered DAX
Machine House 1:
Solar-Powered DAX



DAX External Equipment Case

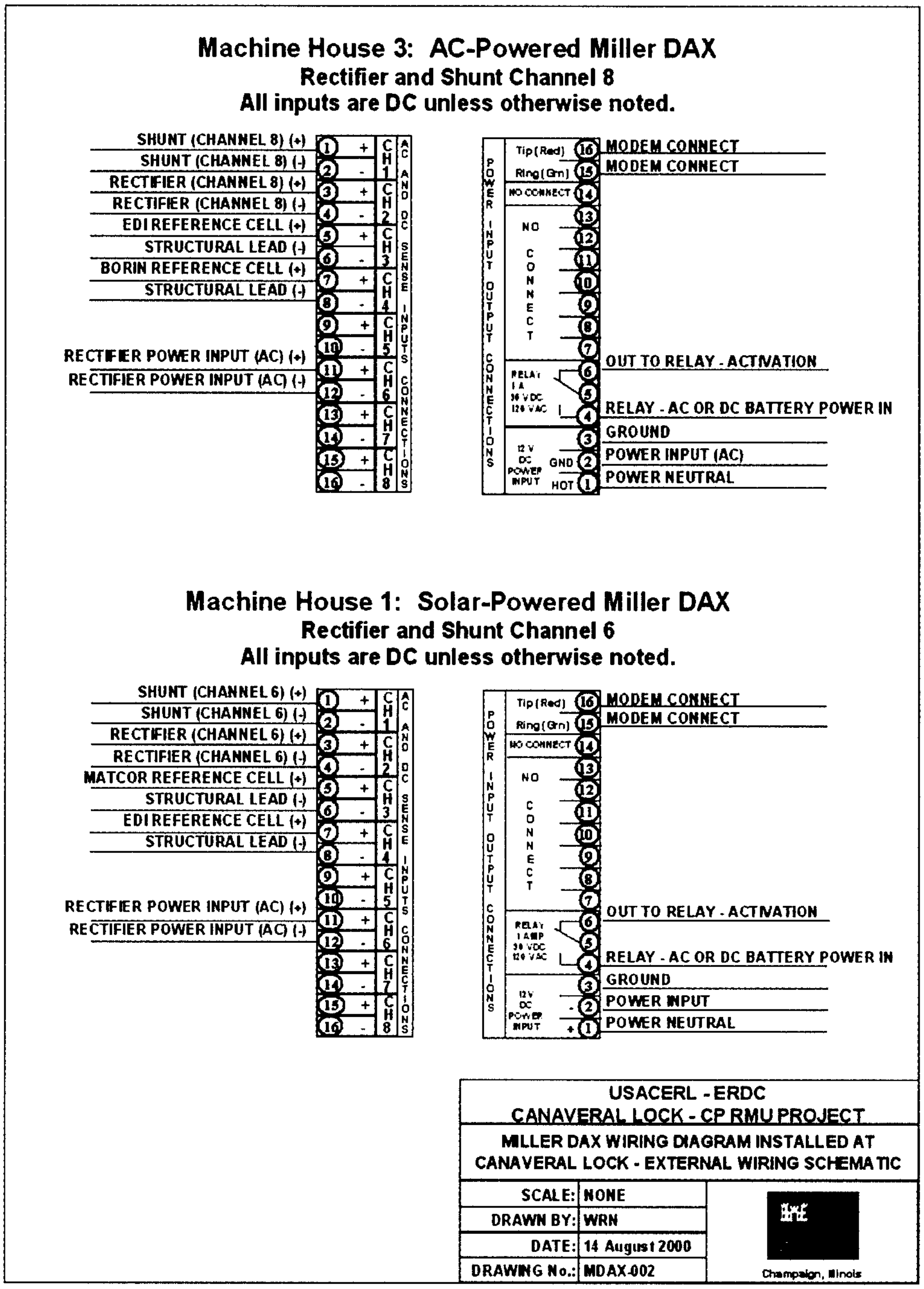


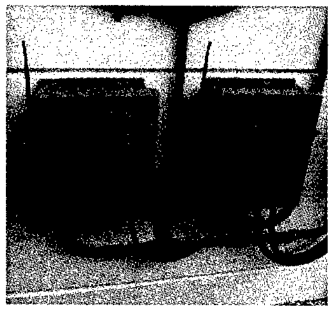
DAX Internal Configuration

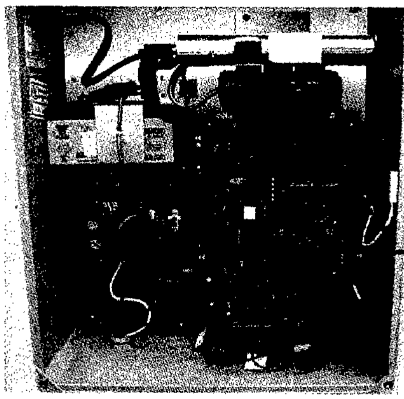


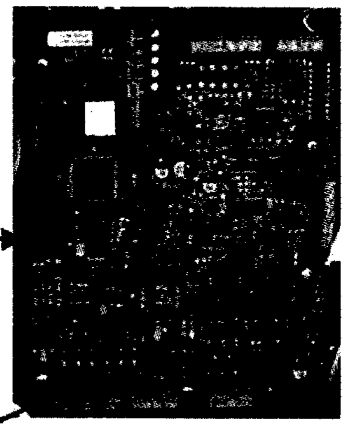
Enlargement of DAX Wiring Terminals

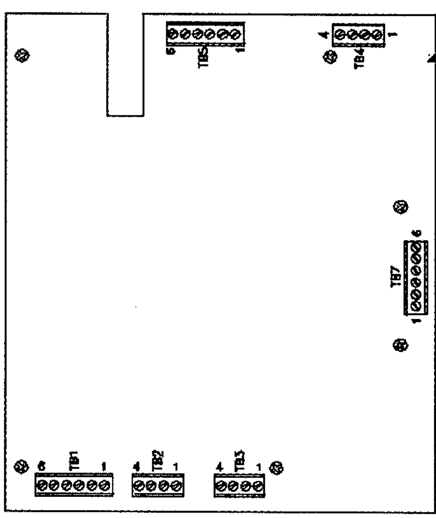
USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT		
MILLER DAX WIRING DIAGRAM INSTALLED AT CANAVERAL LOCK - UNIT SCHEMATIC		
SCALE:	NONE	Champaign, Illinois
DRAWN BY:	WRN	
DATE:	14 August 2000	
DRAWING No.:	MDAX-001	


Machine House 3: AC-Powered Miller DAX
Rectifier and Shunt Channel 8
All inputs are DC unless otherwise noted.
SHUNT (CHANNEL 8) (+)
SHUNT (CHANNEL 8) (-)
RECTIFIER (CHANNEL 8) (+)
RECTIFIER (CHANNEL 8) (-)
EDI REFERENCE CELL (+)
STRUCTURAL LEAD (-)
BORIN REFERENCE CELL (+)
STRUCTURAL LEAD (-)
RECTIFIER POWER INPUT (AC) (+)
RECTIFIER POWER INPUT (AC) (-)
AC AND DC SENSE INPUTS CONNECTIONS
POWER INPUT OUTPUT CONNECTIONS
Tip (Red)
Ring (Grn)
NO CONNECT
NO CONNECT
MODEM CONNECT
MODEM CONNECT
OUT TO RELAY - ACTIVATION
RELAY - AC OR DC BATTERY POWER IN
GROUND
POWER INPUT (AC)
POWER NEUTRAL
12 V DC POWER INPUT
GND
HOT
Machine House 1: Solar-Powered Miller DAX
Rectifier and Shunt Channel 6
All inputs are DC unless otherwise noted.
SHUNT (CHANNEL 6) (+)
SHUNT (CHANNEL 6) (-)
RECTIFIER (CHANNEL 6) (+)
RECTIFIER (CHANNEL 6) (-)
MATCOR REFERENCE CELL (+)
STRUCTURAL LEAD (-)
EDI REFERENCE CELL (+)
STRUCTURAL LEAD (-)
RECTIFIER POWER INPUT (AC) (+)
RECTIFIER POWER INPUT (AC) (-)
MODEM CONNECT
MODEM CONNECT
OUT TO RELAY - ACTIVATION
RELAY - AC OR DC BATTERY POWER IN
GROUND
POWER INPUT
POWER NEUTRAL
USACERL - ERDC
CANAVERAL LOCK - CP RMU PROJECT
MILLER DAX WIRING DIAGRAM INSTALLED AT CANAVERAL LOCK - EXTERNAL WIRING SCHEMATIC
SCALE: NONE
DRAWN BY: WRN
DATE: 14 August 2000
DRAWING No.: MDAX-002
Champaign, Illinois









METRETEK CPM-II
MACHINE HOUSE 1
RECTIFIER AND SHUNT CHANNEL 6
ALL INPUTS ARE DC UNLESS OTHERWISE NOTED.
1. AC-POWERED UNIT ON LEFT SIDE FACING UNITS
2. SOLAR POWERED UNIT ON RIGHT SIDE FACING UNITS WITH DOOR HINGES.

USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT		
METRETEK CPMII WIRING DIAGRAM INSTALLED AT CANAVERAL LOCK - UNIT SCHEMATIC		
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DATE:	14 August 2000	
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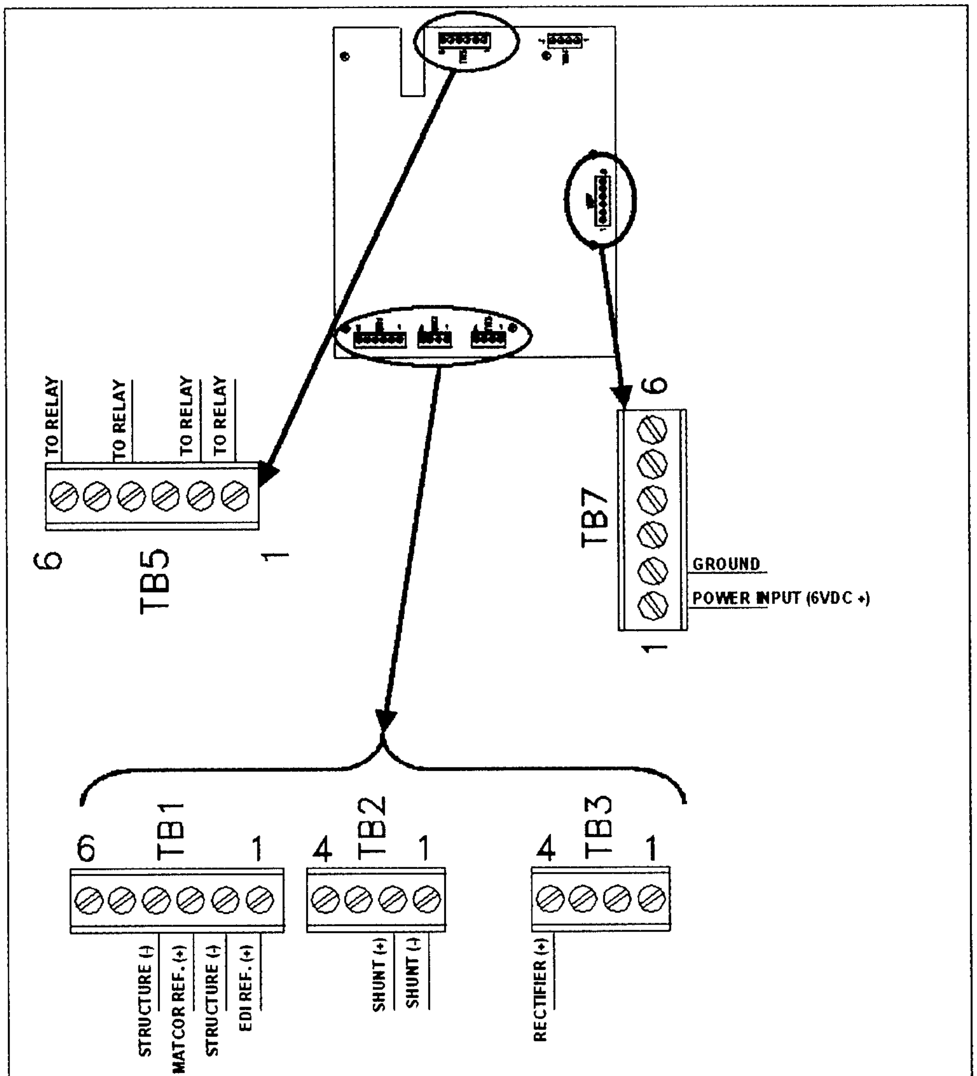

METRETEK CPM-II - AC POWERED
MACHINE HOUSE 1
RECTIFIER AND SHUNT CHANNEL 6
ALL INPUTS ARE DC UNLESS OTHERWISE NOTED.
UNIT ON LEFT SIDE AS SEEN WHILE FACING UNITS

USACERL - ERDC
CANAVERAL LOCK - CP RMU PROJECT

METRETEK CPMII WIRING DIAGRAM INSTALLED AT CANAVERAL LOCK - EXTERNAL WIRING SCHEMATIC

SCALE:	NONE
DRAWN BY:	WRN
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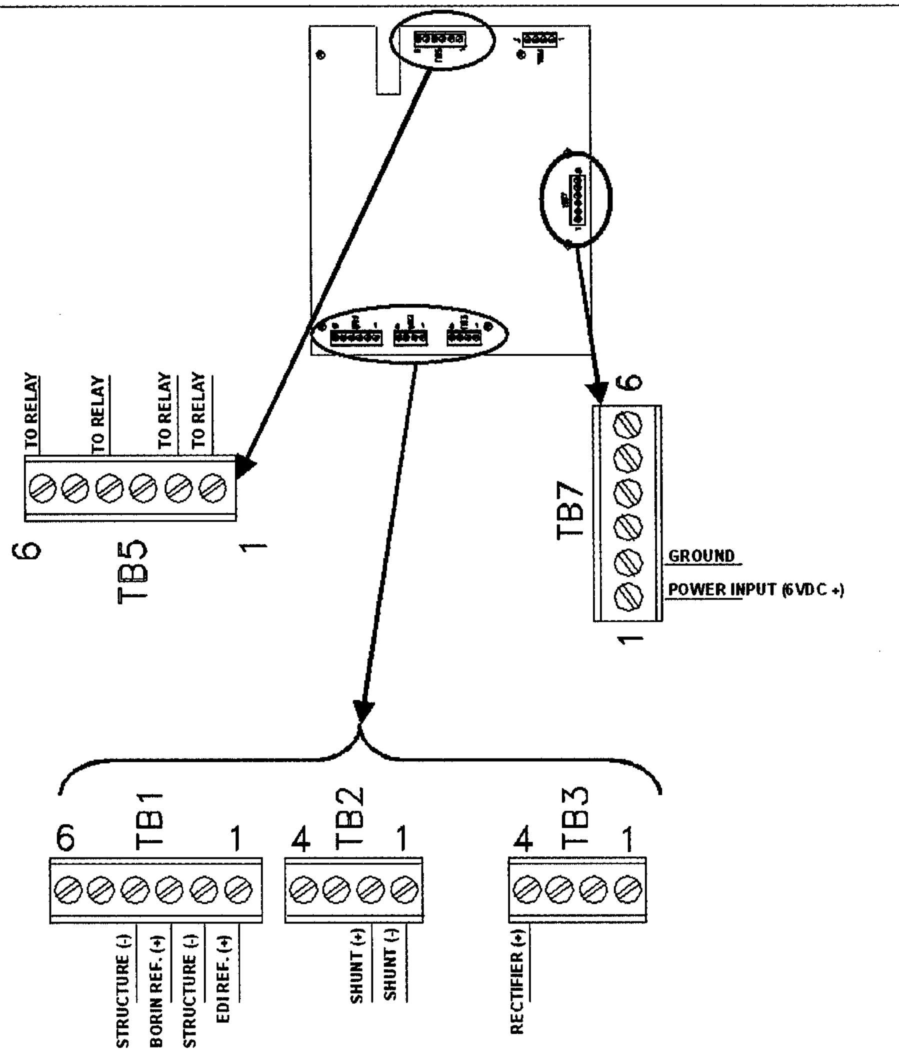

METRETEK CPM-II, SOLAR POWERED
MACHINE HOUSE 1
RECTIFIER AND SHUNT CHANNEL 6
ALL INPUTS ARE DC UNLESS OTHERWISE NOTED.
UNIT ON RIGHT SIDE AS SEEN WHILE FACING UNITS
- COVER IS HINGED

USACERL - ERDC CANAVERAL LOCK - CP RMU PROJECT		
METRETEK CPMII WIRING DIAGRAM INSTALLED AT CANAVERAL LOCK - EXTERNAL WIRING SCHEMATIC		
SCALE:	NONE	
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14. ABSTRACT

Cathodic protection (CP) prevents the corrosion of Corps of Engineers structures such as lock gates, bulkheads, and piers. CP systems must be evaluated and adjusted regularly to make sure that they are providing appropriate levels of corrosion protection. Several companies manufacture systems that are designed to perform this evaluation automatically and/or from a remote location. The objectives of this work were to evaluate commercially available remote monitoring systems to determine their suitability for use on Corps of Engineers Civil Works structures, and to provide equipment selection and implementation guidance for Army Engineer Districts. Three systems were evaluated in the field at Canaveral Lock, Florida, and the results are documented in this report.

15. SUBJECT TERMS
cathodic protection (CP), corrosion control, remote monitoring units (RMUs), corrosion mitigation, civil works structures

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